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THESIS

L3865

PARAMETRIC ANALYSIS OF AIRLAND COMBAT MODEL IN HIGH RESOLUTION

by

Jae Yeong Lee

September 1988

Thesis Advisor: Samuel H. Parry

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by

Lee, Jae Yeong
Major, Republic Of Korea Army
B.S., Korea Military Academy, 1980

Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

A high resolution deterministic combat model is analyzed in this thesis. Actual Republic of Korea (ROK) terrain data is employed in the model. The goal of the thesis is to analyze key parameters which are routinely used in high resolution combat models. These parameters are attrition rate coefficients, force size, courses of action, and the Weiss parameter (in the equation for Helmbold type combat). The model's scenario divides the battlefield into three regions; indirect fire, minefields, and direct fire. Lethality of Firing Theory and Lanchester type differential equations are used to compute unit casualties and unit speed in a discrete time increment. The model's output (unit casualties and survivors, duration of battle, loss exchange rate) are termed of Measures of Effectiveness (MOEs), which are analyzed by Utility Theory and Game Theory methodologies. Sensitivity analysis is applied to each battle option to determine how changes to one or more input parameters affect the model's output. Additionally, the model operates in an interactive mode using network attribute data. The model can easily be expanded or modified to satisfy a user's requirements by adding submodels or changing input data.

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TABLE OF CONTENTS

I. INTRODUCTION 1
  A. BACKGROUND 1
  B. PURPOSE AND GOAL 1
  C. METHODOLOGY 2

II. MODEL DEVELOPMENT 3
  A. SCENARIO 3
    1. General 3
    2. Assumptions 3
  B. ALGORITHM 7
    1. Basic model 7
    2. Units casualties 10
      a. Indirect fire 10
      b. Minefield packages. 13
      c. Direct fire 13
    3. Unit speed 19
      a. Indirect fire and Minefields 19
      b. Direct fire 20
    4. Advanced model 21

III. MODEL OUTPUT ANALYSIS 25
  A. OVERVIEW 25
  B. MEASURES OF EFFECTIVENESS (MOES) 28
  C. COMPARISON BETWEEN BATTLE1 AND BATTLE2 31
  D. UTILITY THEORY 35
    1. General 35
    2. Application 35
      a. Linear Utility 35
      b. Squared Utility 36
      c. Square root Utility 37
  E. GAME THEORY 38

    1. General 38
    2. Application 39
        a. MOE-1 (Red casualties) 39
        b. MOE-2 (Blue survivors) 41
        c. MOE-3 and MOE-4 41
  F. USE OF UTILITY VS GAME THEORY FOR THE ANALYST 43

IV. SENSITIVITY ANALYSIS 44
  A. GENERAL 44
  B. FORCE SIZE 44
  C. ATTRITION RATE COEFFICIENTS 46
    1. Sensitivity for attrition rate coefficients. 46
    2. ANalysis Of VAriance (ANOVA). 49
  D. WEISS PARAMETER 54
  E. COUNTERMEASURES 59
  F. MODEL ENRICHMENT 64

V. SUMMARY AND FUTURE DIRECTIONS 68
  A. SUMMARY 68
  B. FUTURE DIRECTIONS 69

APPENDIX A. MODELS INPUT DATA 70

APPENDIX B. BASIC MODEL 71

APPENDIX C. EXEC FOR BASIC MODEL 86

APPENDIX D. ADVANCED MODEL 87

APPENDIX E. EXEC FOR ADVANCED MODEL 114

LIST OF REFERENCES 115

BIBLIOGRAPHY 116

INITIAL DISTRIBUTION LIST 117

LIST OF TABLES

Table 1. INITIAL FORCE ELEMENTS 3
Table 2. THE MATRIX OF RED AND BLUE OPTIONS 9
Table 3. THE RELATIVE LETHAL AREAS FOR A 155MM HOWITZER . . 12
Table 4. COMPARISON OF MOES BETWEEN BATTLE1 AND BATTLE2 . . 31
Table 5. SENSITIVITIES OF MOES FOR ATTRITION RATE COEFFICIENTS. 48
Table 6. RESULTS OF ONE-WAY ANOVA TEST WHEN THE MAXIMUM ATTRITION RATE COEFFICIENTS ARE CHANGED. 54
Table 7. RESULTS OF ONE-WAY ANOVA TEST WHEN THE WEISS PARAMETER BLUE ENGAGING RED ARE CHANGED. 57
Table 8. PAYOFF MATRIX FOR RED AND BLUE COURSE OF ACTIONS (MOE-1 MOE-2). 61

LIST OF FIGURES

Figure 1. Map of area used in the scenario 4
Figure 2. Network representation of the battle area 5
Figure 3. Flow chart of computer program for the basic model 8
Figure 4. The output of the Basic model (BATTLE2 case) 10
Figure 5. Relation between the defender's casualty rate and the attacker/defender force ratio. 14
Figure 6. Relation between the attacker's casualty rate and the attacker/defender force ratio. 15
Figure 7. Relationship between range and attrition coefficient 17
Figure 8. Battle case when a Blue is threated from two directions 18
Figure 9. Speed of attacking force versus their attrition coefficient 20
Figure 10. Flow chart of the advanced model 22
Figure 11. The output of the advanced model 24
Figure 12. Red and Blue force sizes over time 26
Figure 13. The Red casualties by different types of Blue weapons 27
Figure 14. Distance between Red and Blue forces over time. 28
Figure 15. Speed of Red force on each avenue over time. 29
Figure 16. The MOE values for each options of Red and Blue (BATTLE2) 30
Figure 17. Ratio of MOEs in BATTLE1 types based on BATTLE2 type. 32
Figure 18. MOEs for each options of Red and Blue (BATTLE1 with Avenue-21) . 33
Figure 19. MOEs for each options of Red and Blue (BATTLE1 with Avenue-22) . 34
Figure 20. Three different utility distribution functions. 36
Figure 21. Weighted utility values for each function. 38
Figure 22. Initial matrix and reduced matrix for MOE-1 41
Figure 23. Solution for Value of the Game (MOE-1) 42
Figure 24. Red and Blue force sizes over time when the Blue ambush point is reinforced. 45
Figure 25. Comparison of MOEs when the Blue forces are reinforced. 46
Figure 26. Change of MOE values based on different maximum attrition rate coefficients, a_0 and b_0 47
Figure 27. Ratio of change for MOE values based on different a_0 and b_0 47

Figure 28. Fitting the Red casualties (MOE-1) of the Advanced model output to Normal Distribution. 50
Figure 29. Fitting the Blue survivors (MOE-2) of the Advanced model output to Normal Distribution. 51
Figure 30. MOE outputs for both battle cases; original battle, and both a_0 and b_0 increased by 10 percent. 52
Figure 31. Change of Basic model output (MOE-1 and MOE-2) based on Weiss parameter for Blue engaging Red. 55
Figure 32. Change of Basic model output (Red to Blue casualty ratio and force ratio) based on Weiss parameter for Blue engaging Red. 55
Figure 33. Change of the Basic model output (MOE-1 and MOE-2) when Weiss parameters for both Red and Blue approach the same value. 56
Figure 34. Change of Red Blue casualty and force ratio in Basic model when Weiss parameters for both Red and Blue approach the same value. 56
Figure 35. 3-Dimensional view of payoff matrix for Red casualties. 62
Figure 36. 3-Dimensional view of payoff matrix for Blue survivors. 62
Figure 37. 3-Dimensional view of payoff matrix for the Red to Blue casualty ratio. 63
Figure 38. 3-Dimensional view of payoff matrix for the Red to Blue force ratio. . . 63
Figure 39. Two different functions for minimum speed. 65
Figure 40. Comparison of RED BLUE casualty ratio (MOE-3) between Basic and Enriched model. 66
Figure 41. Comparison of duration of battle (MOE-4) between Basic and Enriched model. 66

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I. INTRODUCTION

A. BACKGROUND

Since the Korean War (1950-1953), the Republic of Korea (ROK) has invested a significant amount of money to defend against the threat posed by North Korea and to maintain a peaceful atmosphere on the Korean Peninsula. As industry and the economy have developed, it has become necessary for the ROK Department of Defense to apply more efficient methods to operate and control the huge defense system. For the Army, one major source of defense expenditure has been in developing different combat simulation models which can be used in ROK's terrain conditions. Unlike the North Atlantic Treaty Organization (NATO) terrain, the Korean peninsula is very complex geographically having many small streams, mountains, hills, and reservoirs. This means it is relatively easy to channalize the enemy's avenues of approach when they attack. Therefore, when the ROK develops an airland combat simulation model, it more precisely and realistically describes the Korean geography than other models. Based on this concept, it is hoped that this thesis will be an useful addition in helping to develop better combat simulation models.

B. PURPOSE AND GOAL

The purpose of this thesis is to analyze the parameters which are heavily used in high resolution airland combat models. As the deterministic model is developed, a common scenario is used to approach this goal. In this scenario, Red (enemy force) attacks Blue (friendly force) through an arbitrary terrain network giving Red a number of different routing options. It is assumed that Red can take limited avenues of approach since the maneuverability of Red is restricted to certain arcs (routes) due to destroyed bridges or a strong probability of ambush.

Specifically, the goal of this thesis is to suggest the best courses of action for the Blue commander based upon various types of airland battle situations and to demonstrate several decision methods from an analytic viewpoint. The model developed here can be easily modified and applied to test other battle situations if one has more precise terrain data.

C. METHODOLOGY

To build a scenario, an area in ROK near the Demilitarized Zone (DMZ) was selected and a network was developed having several possible paths for Red forces based upon the road conditions of that actual terrain area. Generally, Red attempts to attack Blue's fortified positions through the shortest distance path or shortest time path. There are several methodologies available to find these paths. This effort will incorporate methodologies previously explored by the AirLand Rearch Model (ALARM) at the Naval Postgraduate School. The use of network methodology to model terrain was developed by Craig [Ref. 1] and McLaughlin [Ref. 2]. The determination of network attributes from a high resolution terrain data base was developed by Choi [Ref. 3 : p. 27].

Regard each intersection of the roads as a node and the road between the nodes as an arc, and add the speed, distance, and width to estimate the trafficability of each arc. This information is to be used as inputs for the models. In this deterministic model, single round lethality of Firing Theory is adopted for artillery fire in the beginning of the battle. Lanchester's Linear Law is used for casualties in the minefields. Hembold equations are used for direct fire as well as range dependency and ambush attack. It is also assumed that the speed of the Red force depends on their attrition rate coefficient caused by the Blue force. In other words, Red's speed is a function of Blue's attrition rate coefficient on Red, since the mauverability of the Red force will decrease as they get closer to the Blue positions. This will be explained in more detail in Chapter 2.

Based on the several options available to each side, the battle situations are changed to derive the different outputs. If the Red force has M options and Blue has N options, the output can be desciibed by an M by N matrix of each specific value which can be compared and analyzed. These matrices could be Red casualties, Blue survivors, time of the battle, or the ratio of Red and Blue casualties. Because these values are very significant factors of the battle, they are defined as the values of Measures Of Effectiveness (MOEs). After generating the required matrices of MOEs, they were analyzed using the techniques of Utility Theory and Game Theory. Additionally, sensitivity analysis was also conducted for selected parameters.

II. MODEL DEVELOPMENT

A. SCENARIO

1. General

The Red regiment has three infantry battalions and one reserve company and the Blue battalion has three infantry companies and one reconnaissance platoon. Blue commander can employ its reconnaissance platoon for a special mission. In the model, the reconnaissance platoon of Blue will ambush Red on the most important avenue of approach and Blue will defend from two well fortified positions (Node-27, Node-28 in Figure 2). The battle will terminate if one of the Red forces reaches either of these two nodes. Only infantry forces were considered in the initial runs of the model. Initial force elements of both sides are shown in Table 1.

Table 1. INITIAL FORCE ELEMENTS

	Red force		Blue force	
	3 battalions :	1500	3 companies :	510
	1 reserve co.:	150	1 recon. pltn. :	40
Total		1650		550

- unit = infantryman.

The battle area in this scenario is taken from one of the ROK Army divisions' assigned sectors. This area is relatively flat except for one large mountain, Geumhag San, which is located in the west central part of the battle area. One small river, Daegyo Cheon, which flows from the northwest to the southeast, poses no significant problem to the Red force when attacking with either mounted or dismounted units. The map of this terrain area is shown in Figure 1 and a representation of the network in terms of arcs and nodes is shown in Figure 2.

2. Assumptions

The assumptions and description of the scenario are as follows:

1. There are three major avenues of approach for the Red force.
2. The Red force on the second avenue (center) will be divided at node-14, with two equal forces and attack to nodes 27 and 28, respectively (This assumption could

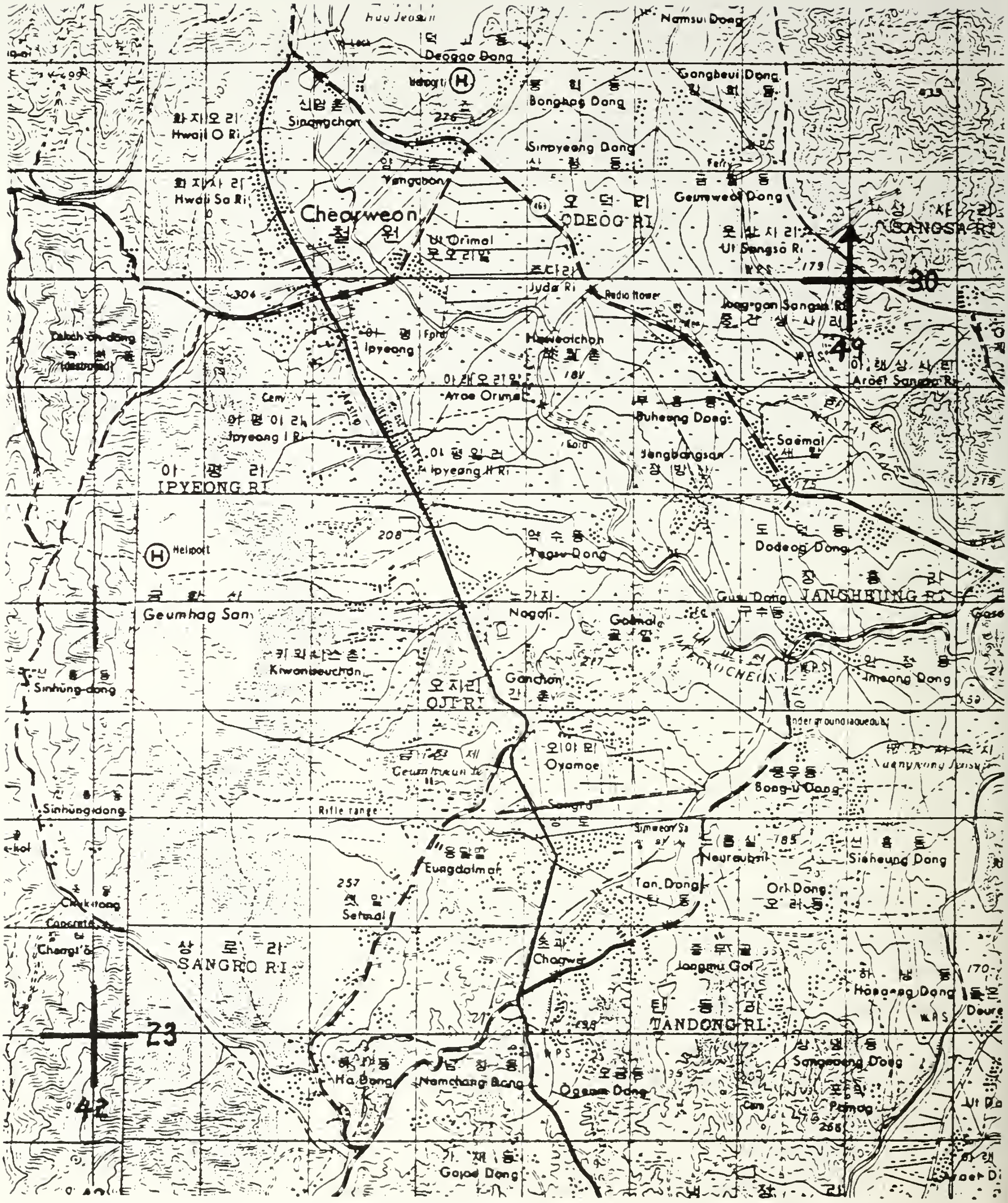

Figure 1. Map of area used in the scenario

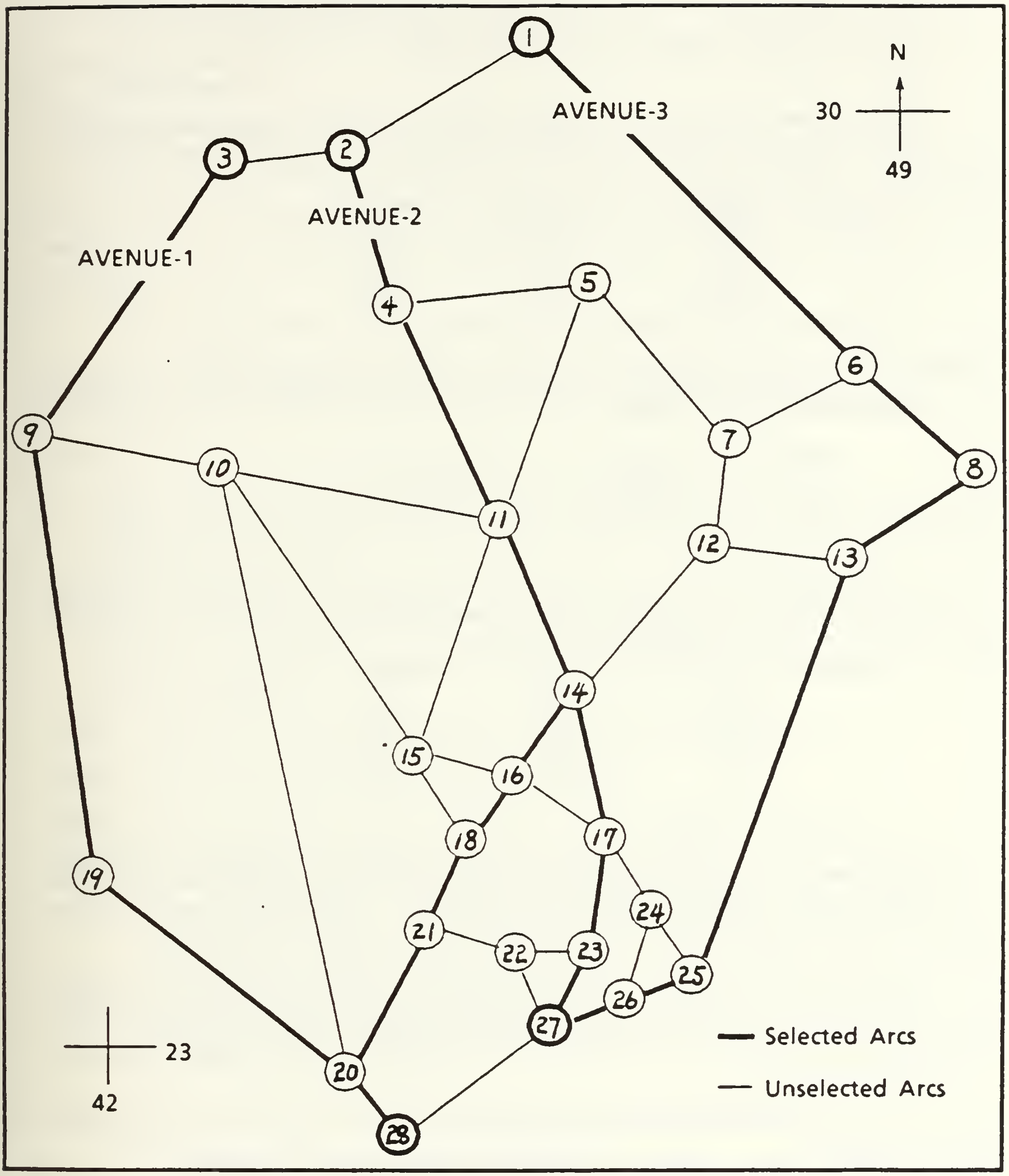

Figure 2. Network representation of the battle area

be changed so that the Red force on the second avenue will attack only one of two Blue positions as described in Chapter 3). Therefore, denote Avenue-21 used by Red attacking to node-28 and Avenue-22 used by Red attacking to node-27.

3. Red force initiates maneuver from their boundary at the same time (from nodes 1,2,3).

4. Red force has four options to allocate their units (battalions) for each avenue of approach, where attacker (Red) actions are treated as states of nature, as follows:

Option	Avenue-1	Avenue-2	Avenue-3
1.	1 Bn.	1 Bn.	1 Bn.
2.	0 Bn.	2 Bn.	1 Bn.
3.	0 Bn.	1 Bn.	2 Bn.
4.	0 Bn.	3 Bn.	0 Bn.

5. Blue force has two options to allocate their units (companies) for each fortified defense positions as follows:

Option	Fort-1(node 27)	Fort-2(node 28)
1.	1 Co.	2 Co.
2.	2 Co.	1 Co.

6. Blue force has four options for how to allocate the three scatterable mine packages they currently possess. Those options are as follows:

Option	Avenue-1	Avenue-2	Avenue-3
1.	1 Pkg.	1 Pkg.	1 Pkg.
2.	0 Pkg.	2 Pkg.	1 Pkg.
3.	0 Pkg.	1 Pkg.	2 Pkg.
4.	0 Pkg.	3 Pkg.	0 Pkg.

7. The number of Red units (battalions) affect the speed of attacking Red forces on each avenue. This implies that Red moves with reduced speed when there are multiple units on one of the avenues of approach. The Red forces also become more dense in a given area when multiple units are on one avenue.

8. Whenever the Red force reaches a minefield, it takes more time to bypass than to break through. Therefore, the Red force will choose to break through.

9. The only artillery weapon system that supports the Blue force is the 155 millimeter howitzer (towed).

10. Red indirect fire weapons are not represented.

11. Blue has two types of minefield packages: preinstalled and scatterable.

12. The maximum range for infantry direct-fire weapons is 1.1 km (M60 machine gun).

13. There are no Close Air Support (CAS) aircraft or chemical weapons employed in this scenario.

As described above, Red has four options and Blue has eight options. Therefore, there are 32 battle cases in this scenario.

B. ALGORITHM

1. Basic model

The rule for representing the battle is based on discrete time steps. The battle clock will begin when the Red force attacks from their original locations, which are nodes 1, 2, and 3 in the network representation of Figure 2. The time step interval is one minute.

The basic model is only one of the possible battle cases in this scenario, that is, one option for Red and one option for Blue which represent one element out of the 4 by 8 matrix. These options may be entered interactively. The basic model steps are described below:

- ***Input*** : Characteristics of the network terrain model which include source node (tail node), sink node (head node), arc number, distance and speed on each arc, location of minefield, and amount of time for indirect fire. An example of input format is included in Appendix A.
- ***Output*** : Characteristics of battle results which include casualties and survivors for both sides, the length of battle, proportion of casualties based on weapon types (indirect fire, minefield, direct fire), avenues of approach, and positions (nodes) of the the Blue forces.

Step 1 : Read the input data and initialize the forces, time, location etc..

Step 2 : Set the battle clock to the next time step

Step 3 : Detect the weapon type such as indirect fire, minefield and direct fire.

Step 4 : Compute the casualties and survivors for each weapon type based on Step 3.

Step 5 : Determine the speed of the attacking force and compute the distance it moved during that time step. It is assumed that the speed of Red forces is affected by indirect fire, minefields, and direct fire.

Step 6 : Consider battle termination conditions and decide whether the battle will continue or not. If the battle does not terminate, go to Step 2. If the battle terminates, print the output.

All these steps occur independently and simultaneously on each avenue.

The flowchart of the basic model is given in Figure 3, and the following definitions apply:

IF = Indirect Fire battle

MF = Minefield acquisition

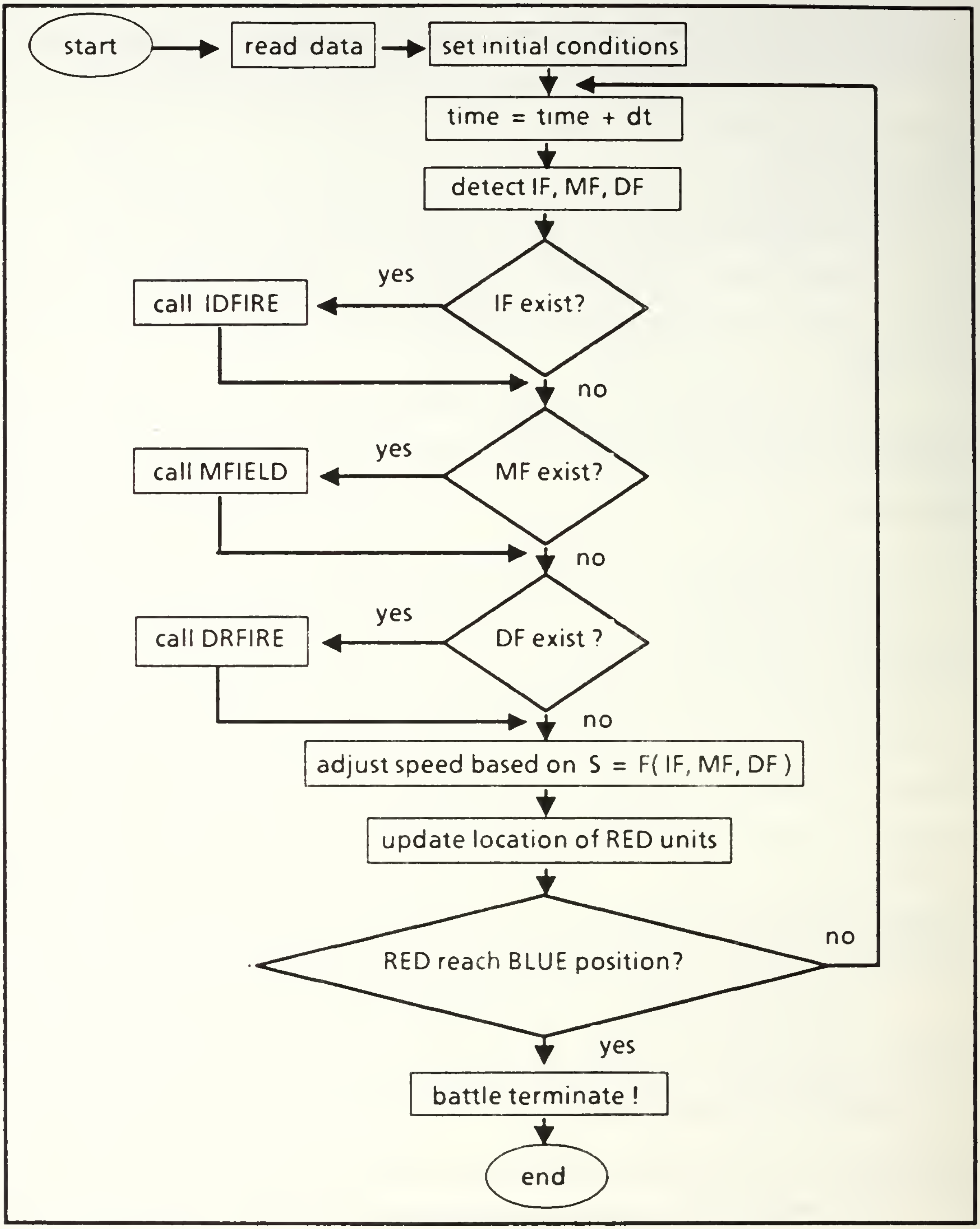

Figure 3. Flow chart of computer program for the basic model

DF = Direct Fire battle

IDFIRE = subroutine for computing the casualties by indirect fire.

MFIELD = subroutine for computing the casualties by minefield.

DRFIRE = subroutine for computing the casualties by direct fire.

The table for Red and Blue options can be represented as a 4 by 8 matrix (see Table 2).

Table 2. THE MATRIX OF RED AND BLUE OPTIONS

Options			Red's unit allocation on each avenue			
			1 1 1	0 2 1	0 1 2	0 3 0
Blue's unit allocation (1 2)	Scatterable mine allocation on each avenue	1 1 1	O_{11}	O_{12}	O_{13}	O_{14}
		0 2 1	O_{21}	O_{22}	O_{23}	O_{24}
		0 1 2	O_{31}	O_{32}	O_{33}	O_{34}
		0 3 0	O_{41}	O_{42}	O_{43}	O_{44}
Blue's unit allocation (2 1)	Scatterable mine allocation on each avenue	1 1 1	O_{51}	O_{52}	O_{53}	O_{54}
		0 2 1	O_{61}	O_{62}	O_{63}	O_{64}
		0 1 2	O_{71}	O_{72}	O_{73}	O_{74}
		0 3 0	O_{81}	O_{82}	O_{83}	O_{84}

As presented in Table 2, the Red force has four options based on its unit allocation, and the Blue force has eight options which represent all possible combinations of unit allocation with scatterable mine allocation (see assumptions 4, 5, and 6 previously discussed). Based on the Blue commander's tactical viewpoint and considering the geographical situations, the O_{22} (option-2 for Red and option-2 for Blue) battle case could be expected to occur in a real battle situation with higher probability than the other cases. Thus, O_{22} case was executed as an example output of the basic model and the results are shown in Figure 4.

In Figure 4, the numeric values corresponding to the Red and Blue options are the number of troop units or minefield packages (i.e., Bn, Co, Pkg) each allocates to each avenue of approach or position. These values remind the user of what he has entered interactively. In fact, this output shows precisely how the battle terminated and what the results are for each Blue position. A computer program of the basic model is provided in Appendix B.

```
RED OPTION ===>    0  2  1
BLUE OPTION
   * SCATERABLE MINEFIELD ===>  0  2  1
      (LOCATED ON ARCS)  ===> 30 34 42
   * FORCE ALLOCATION =======>  1  2


RED FORCE IN AVE#22 TOOK BLUE POSITION#2 : BATTLE END !
    (BATTLE TIME ===>  225 MINUTES)


    <<< RED CASUALTIES BY EACH TYPE OF BLUE FORCE >>>
------------------------------------------------------------
              INDIRECT-FIRE    MINE-FIELD    DIRECT-FIRE
------------------------------------------------------------
  AVENUE#1          0.0              0.0             0.0
  AVENUE#21        23.4             47.1           163.0
  AVENUE#22        23.4             47.0           406.2
  AVENUE#3          0.0             22.2            19.4
------------------------------------------------------------
                   46.8            116.3           588.6


    <<< BLUE FORCE CASUALTIES FOR EACH POSITION >>>
------------------------------------------------------------
                CASUALTIES      SURVIVORS
------------------------------------------------------------
  POSITION-1       55.7           134.3
  POSITION-2      186.7           173.3
------------------------------------------------------------


    <<< TOTAL CASUALTIES AND SURVIVORS >>>
------------------------------------------------------------
              INITIAL FORCE     CASUALTIES       SURVIVORS
------------------------------------------------------------
    RED         1650.0            751.7            898.3
    BLUE         550.0            242.4            307.6
------------------------------------------------------------
```

Figure 4. The output of the Basic model (BATTLE2 case)

2. Units casualties

a. Indirect fire

Casualties caused by indirect fire weapons are computed using single round lethalty and weapon firing rates. Target density is a major factor in computing casualties and is defined as the distance between adjacent soldiers. The dispersion between troops decreases as Red allocates more than one unit (battalion) to one avenue. In other words, the number of Red infantrymen in a given area will increase. Also, in this model, the targets are represented as two dimensional, which means that an artillery projectile is represented as detonating on the ground, not in the air. A target under attack by artillery could consist of many personnel performing various functions of combat, and such consideration is taken into acount in the computation of lethality. Lethal areas are computed for single conditions such as prone personnel. The definition of lethal area A_L is given by equation (2.1).

$$A_L = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} p(x, y|H)\, dxdy \tag{2.1}$$

where p(x,y|H) is the conditional probability that a hit on a target element located at the point (x,y) on the ground results in an incapacitation for given height of burst H (H = 0 in this model) [Ref. 4 : p. 14-9].

Using the Gaussian Lethality Function p(x,y|H) = $e^{-(x^2+y^2)/2\sigma^2}$, and transforming into polar coordinates, equation (2.1) becomes equation (2.2).

$$A_L = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} e^{-(x^2+y^2)/2a^2}\, dxdy$$

$$= \int_{0}^{2\pi} \int_{0}^{+\infty} e^{-r^2/2a^2}\, rdrd\theta \;=\; 2\pi a^2 \qquad where \;\; r^2 = \sqrt{x^2 + y^2} \tag{2.2}$$

A Red infantryman is assumed to be killed if he is within the lethal area. Thus, the probability of kill is the probability of hitting the lethal area multiplied by the proportion of lethal area of the entire target area, given in equation (2.3).

$$P(kill) = P(hit) \times Prop(lethal) \tag{2.3}$$

The Prop(lethal) is calculated by dividing the total area of the Red force by the total lethal area per unit time from equation (2.4), and P(hit) is computed for a two-dimensional target by equation (2.5).

$$Prop(lethal) = \frac{R_f \times A_L}{Row_{sp} \times Col_{sp} \times RF_c} \tag{2.4}$$

where

R_f : rate of fire per unit time

A_L : lethal area of each round

Row_{sp} : row spacing of each unit (infantrymen)

Col_{sp} : column spacing of each unit (infantrymen)

RF_c : current Red force size

$$P(hit) = \frac{a^2}{[(a^2 + \sigma_x^2)\,(a^2 + \sigma_y^2)]^{1/2}} \ \exp\left[-\frac{1}{2} \ \{ (\frac{\mu_x^2}{a^2 + \sigma_x^2})^2 + (\frac{\mu_y^2}{a^2 + \sigma_y^2})^2 \} \right] \tag{2.5}$$

where

a : lethality constant for each round type (where Total $A_L = 2\pi a^2$)

μ_x : mean distance of deflection error

μ_y : mean distance of range error

σ_x : standard deviation of deflection error

σ_y : standard deviation of range error

Finally, the casualties by indirect fire per unit time (IF_{cas}) are computed by equation (2.6) based on equations (2.3) through (2.5).

$$IF_{cas} = P(kill) \times RF_c \tag{2.6}$$

Table 3. THE RELATIVE LETHAL AREAS FOR A 155MM HOWITZER

Weapon and Caliber	Projectile	Area for Personnel (Open/Woods : m^2)		
		Standing	Prone	Foxhole
M109A1 155-mm	M107	103/42.5	70.8/22.3	6.67/2.0
	M483	981/580	508/308	14.2/9.5
	M549	100/44.8	82.2/26.0	1.50/0.83

The source for 155 milimeter howitzer lethalty data is [Ref. 4 : p. 43-9] which is shown in Table 3 for a range of 14km. For example, the value of a single round lethal area,

$70.8m^2$, is used when the Red force is in the prone position and is subjected to Blue indirect fire attack in the open.

b. Minefield packages.

It is assumed that the Blue force has five preinstalled minefield packages: one on Avenue-1, three on Avenue-2, and one on Avenue-3. Scatterable minefield packages are also employed by the Blue commander. The area fire assumptions of the "Lanchester Linear Law" are generally applied to indirect fire patterns of artillery. Minefields also exhibit these same patterns, and therefore the Lanchester Linear Law equations are appropriate for assuming minefield attrition. The equation for preinstalled minefield casualties is given in equation (2.7).

$$PMF_{cas} = P_{coef} \times N_{red} \times NP_{mine} \times T_p \tag{2.7}$$

The equation for scatterable minefield casualties is shown in equation (2.8).

$$SMF_{cas} = S_{coef} \times N_{red} \times NS_{mine} \times T_s \tag{2.8}$$

where

PMF_{cas} : number of casualties by preinstalled minefield
SMF_{cas} : number of casualties by scatterable minefield
P_{coef} : attrition coefficient of preinstalled minefield
S_{coef} : attrition coefficient of scatterable minefield
NP_{mine} : number of mines in one preinstalled minefield
NS_{mine} : number of mines in one scatterable minefield
T_p : time to traverse a preinstalled minefield
T_s : time to traverse a scatterable minefield
N_{red} : number of infantrymen traversing the minefield

The time to traverse each minefield is a constant value. When the Red force moves on an arc that has a minefield, Red's traversing time on that arc is increased by the amount of time needed to traverse the minefield. However, Red's speed on that arc decreases based upon the time to traverse the minefield, which will be discussed in detail in section *3*.

c. Direct fire

Based on consideration of historical combat data, Helmbold has proposed a modification of Lanchester's equation for "modern warfare" to account for inefficien-

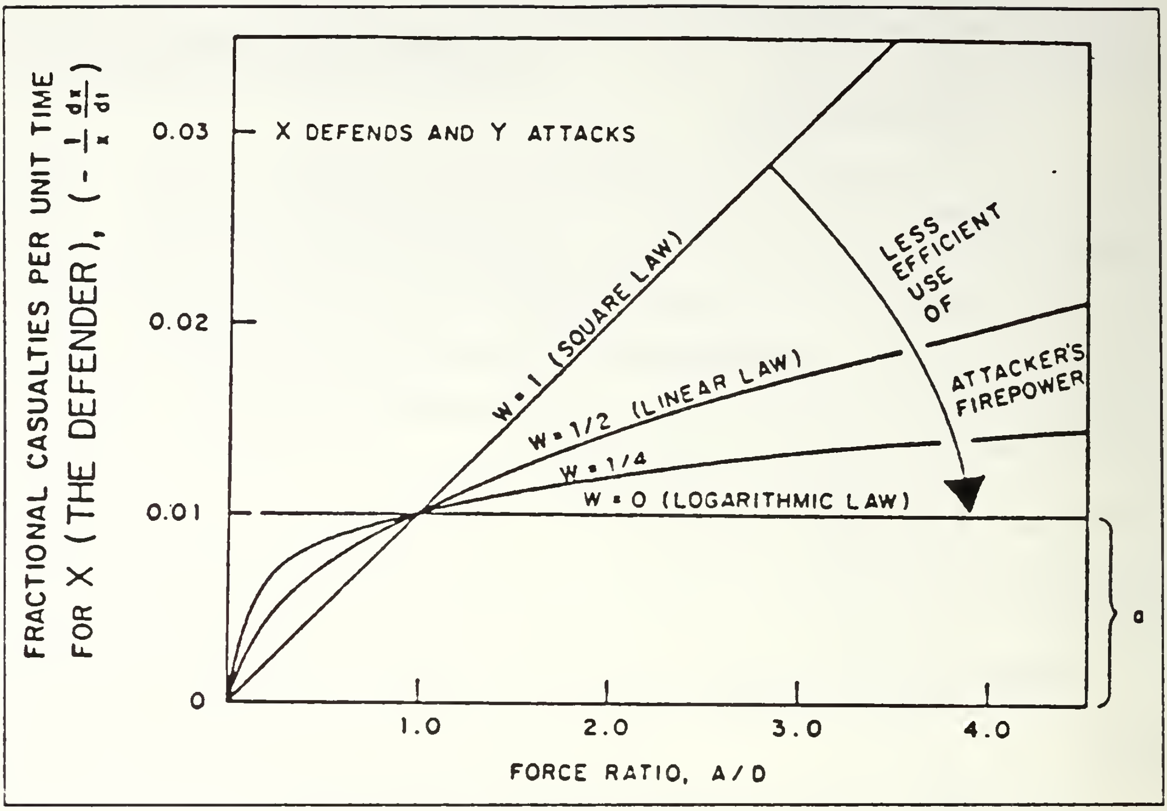

Figure 5. Relation between the defender's casualty rate and the attacker/defender force ratio. [NOTE: In the above figure, A denotes the attacker's force level, and D denotes that of the defender].

cies of scale for the larger force when force sizes are grossly unequal. His basic idea is to modify the relative force attrition (or fire effectiveness) capability by a multiplicative factor depending on only the force ratio. Helmbold considered the special case in which the fire effectiveness modification factor is a power function. In this case, the casualty rates of X and Y are

$$\frac{dx}{dt} = -a(t)\left(\frac{x}{y}\right)^{1-\omega} y \qquad \text{with} \quad x(0) = x_0 \tag{2.9}$$

$$\frac{dy}{dt} = -b(t)\left(\frac{y}{x}\right)^{1-\omega} x \qquad \text{with} \quad y(0) = y_0 \tag{2.10}$$

where w is called the *Weiss parameter*, and equations (2.9) and (2.10) are called the *equations for Helmbold type combat*.

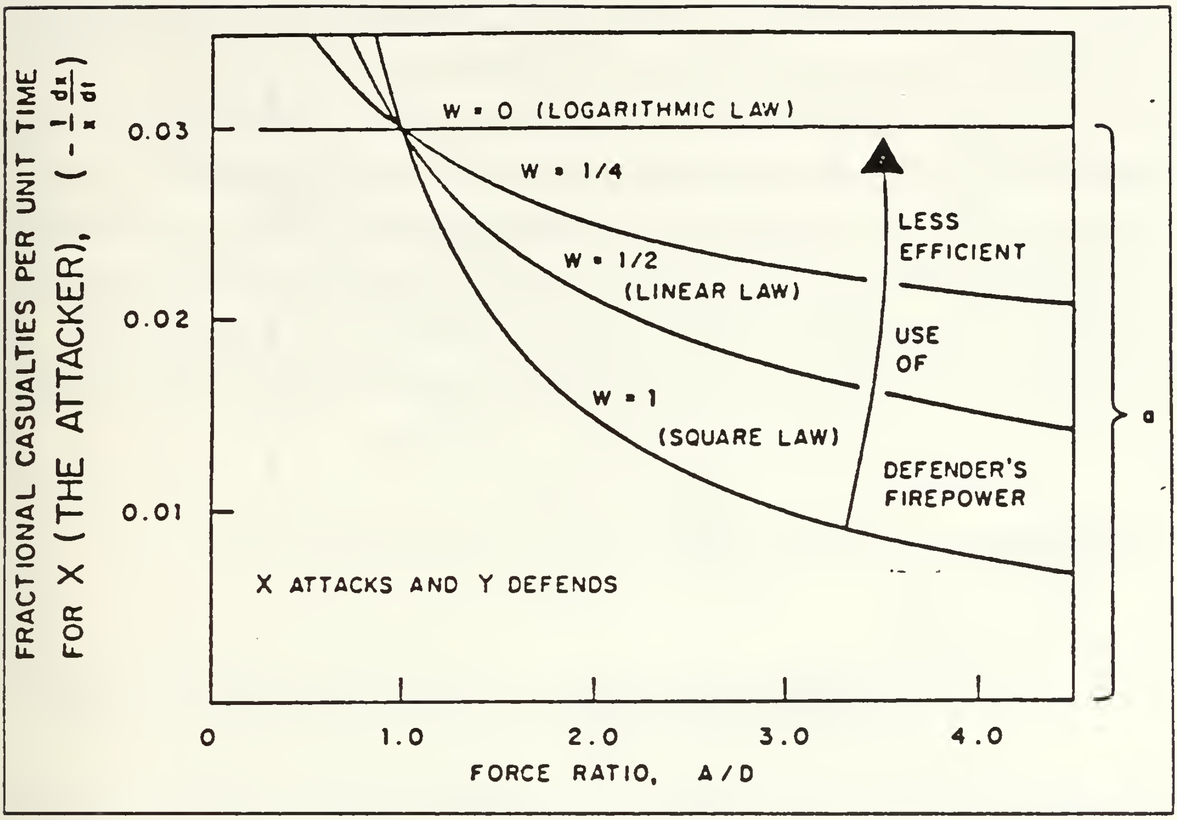

Figure 6. Relation between the attacker's casualty rate and the attacker/defender force ratio.

These equations are particularly significant because a simple generalization of them gives a much better fit to casualty rate curves used in several important contemporary large scale combat models than does Lanchester's classic model of modern warfare. As for the case of constant attrition rate coefficients (i.e., "a(t)" and "b(t)" from equations (2.9) and (2.10) become "a" and "b"), the equations for Helmbold type combat yield the Square Law when $w = 1$, the Linear Law when $w = 1/2$, and the Logarithmic Law when $w = 0$.

Figure 5 shows the relation between the defender's casualty rate (expressed as a fraction of his current force level, x(t)) and the attacker/defender force ratio for the model $dx/dt = -a(x/y)^{1-w}\, y$ with X defending. Figure 5 is X's fractional casualties plotted per unit time versus the force ratio y/x (denoted in the figure as A/D) for the case in which Y attacks and X defends. In Figure 5, w = 1 corresponds to the case in which X's casualty rate is proportional only to the number of enemy firers, and (in the symmetric case in which Y's casualty rate has the same functional form) consequently the corresponding attrition model is given by Lanchester's Square Law equation. We observe that in this case (i.e., w = 1) X's fractional casualties per unit time are directly proportional to the force ratio A/D when Y attacks and X defends. Refering to equation (2.9), we see that $w = w_1$ corresponds to a more efficient use of the attacker's firepower for force ratios A/D = y/x > 1 than does $w = w_2$ when $1 \geq w_1 > w_2$, since the attacker's fire effectiveness modification factor for $w = w_1$ (i.e., $(x/y)^{1-w_1}$) is greater than that for $w = w_2$ when y/x > 1 [Ref. 5 : p. 299]. The following is a numerical example for Figure 5.

<EXAMPLE>

Let a = 0.010
b = 0.020
x = 10 (defender force size)
y = 30 (attacker force size)
hence, attacker to defender force ratio A/D = y/x = 3.0

Using equation (2.9), fractional casualties per unit time for X (the defender) are as follows:

	w=1	w=1/2	w=1/4	w=0
-dx/dt	0.300	0.173	0.132	0.100
-(1/x)(dx/dt)	0.030	0.0173	0.0132	0.010

Figure 6 shows the same type of plot when X is the attacker and Y is the defender. In this case, the casualty-rate curve corresponding to the Square Law is a hyperbola. Note, the smaller the value w ($0 \leq w \leq 1$), less efficient use of defender's firepower is made when attacker to defender force ratio (A/D) is greater than 1.0. However, the reverse phenomenon occurs when A/D is less than 1.0.

The strength of the equations for Helmbold type combat is that it easily incorporates either area fire or aimed fire with the Weiss parameter, "w". These

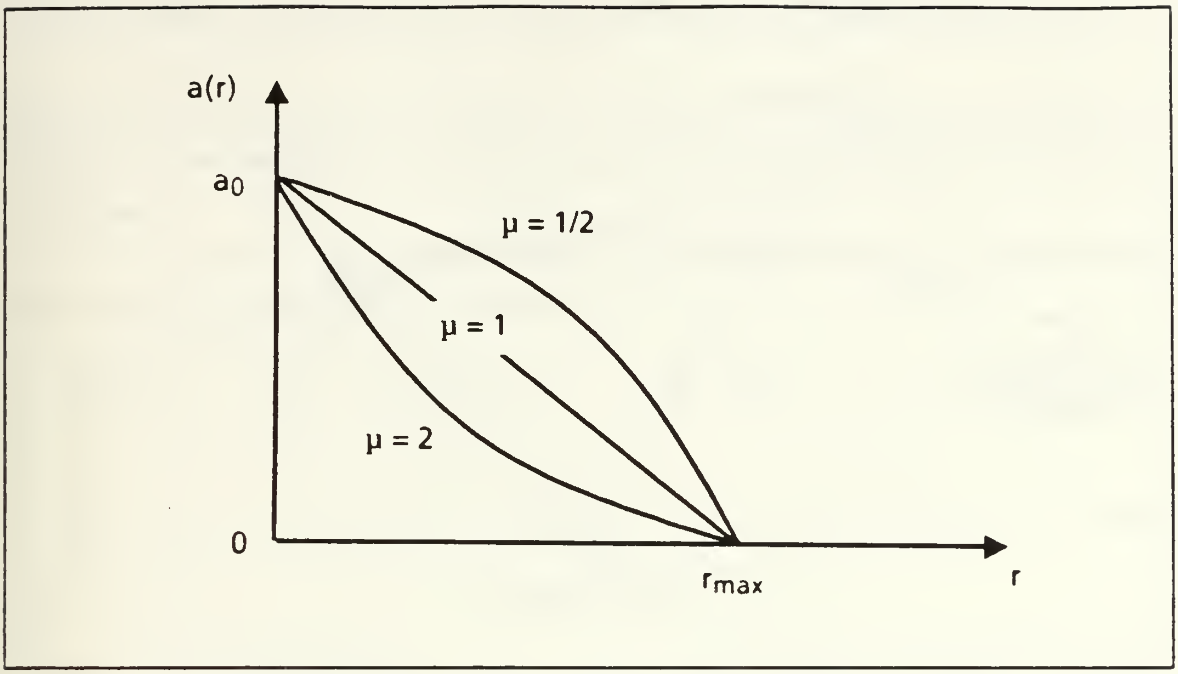

Figure 7. Relationship between range and attrition coefficient

equations are based on the perception that limitations in space, terrain masking and target engagement opportunities prevent a large force from using its full firepower. This deterministic model uses these Helmbold type combat equations for direct fire from fortified Blue positions (node 27 and 28), and the Lanchester's Mixed Law (which is the special case of Helmbold type combat where $w = 1$ for one side and $w = 1/2$ for the other) is utilized for ambushes on arc-19 of the second avenue of approach. The ambush point is determined by the Blue commander. The ambushes will terminate when the Red forces reach the Blue ambush point, and Blue survivors will retreat to join their main forces at node-27 or node-28.

The range dependency is considered for both cases (at nodes 27 and 28, and the ambush point). This implies that attrition rate coefficients for each side increase as the Red force approaches the Blue position. Plotting attrition rate coefficients as a function of range shows how different values of μ (power factor based on different weapon types) affect battle outcomes. Figure 7 shows the relationship between range and attrition coefficients.

A common tactic that is employed to counter multiple Red forces approaching a Blue position is discussed next. Each Blue position has two possible ave-

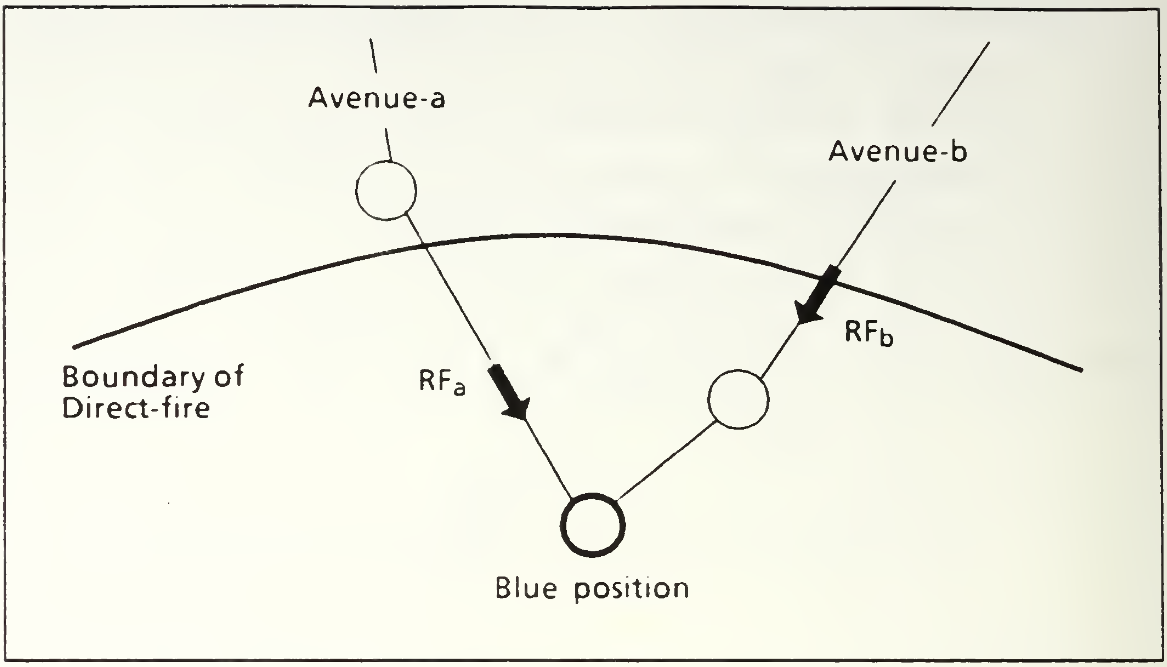

Figure 8. Battle case when a Blue is threated from two directions

nues of approach: Avenue-1 and Avenue-21 for node-28, and Avenue-22 and Avenue-3 for node-27. If a Blue position is threated simultaneously from both avenues of approach within its direct fire region, Blue allocates firepower based on the proportion of Red forces on that avenue of approach. The number of Blue forces firing on *Avenue-a* are given by equation (2.11)

$$BF_a = BF_0 \times \frac{RF_a}{RF_a + RF_b} \tag{2.11}$$

The number of Blue forces firing on *Avenue-b* are given by equation (2.12)

$$BF_b = BF_0 \times \frac{RF_b}{RF_a + RF_b} \tag{2.12}$$

where

BF_a : Blue forces firing into Avenue-a
BF_b : Blue forces firing into Avenue-b
RF_a : Red forces attacking from Avenue-a
RF_b : Red forces attacking from Avenue-b

BF_0 : Blue forces at the moment two Red forces engage a Blue position.

Once the Blue force allocates its firepower, it continues at a steady rate until battle termination. Figure 8 depicts a Blue position being attacked by Red units on two avenues of approach.

The following equations used in this deterministic model represent both range dependency and the Weiss parameter.

$$\frac{dx}{dt} = -a_0 \left(1 - \frac{r_c}{r_{\max}}\right)^{\mu_y} \left(\frac{x}{y}\right)^{1-\omega_y} y \tag{2.13}$$

$$\frac{dy}{dt} = -b_0 \left(1 - \frac{r_c}{r_{\max}}\right)^{\mu_x} \left(\frac{y}{x}\right)^{1-\omega_x} x \tag{2.14}$$

where

x : Red force size

y : Blue force size

a_0 : maximum attrition rate coefficient to Red from Blue

b_0 : maximum attrition rate coefficient to Blue from Red

r_c : current range between Red force and Blue force

$r_{\max}$: maximum range between the Red force and the Blue force (1.1 Km by assumption).

μ_y : power factor, based on Blue weapon types

μ_x : power factor, based on Red weapon types

ω_y : measure of efficiency which the Blue force engages the Red force.

ω_x : measure of efficiency which the Red force engages the Blue force.

Equation (2.13) is used for Red casualties while equation (2.14) is used for Blue casualties during a specific time step. Note that different values of μ and ω are used for the Red and the Blue force.

3. Unit speed

a. *Indirect fire and Minefields*

When Red forces move over the arcs which have indirect fire or minefields, they are delayed for a specified amount of time. If the delay time is denoted by DT, the updated speed is computed by equation (2.15).

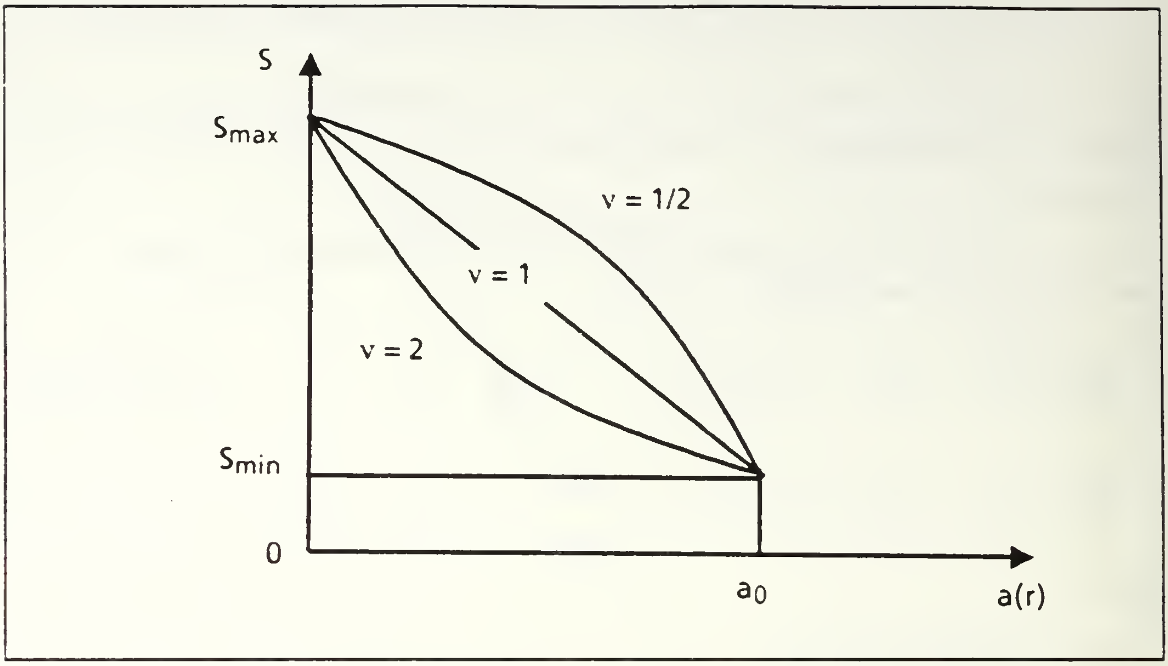

Figure 9. Speed of attacking force versus their attrition coefficient [S vs a(r)].

$$S_{new} = \frac{DIST(\text{arc}_i)}{TIME(\text{arc}_i) + DT_i} \qquad i = a, b, c \qquad (2.15)$$

where

$\text{DIST}(\text{arc}_i)$: distance of arc_i

$\text{TIME}(\text{arc}_i)$: amount of time to transit arc_i

DT_i : delay time on arc_i

arc_a : arcs which are being subjected to indirect fire

arc_b : arcs which have preinstalled minefields

arc_c : arcs which have scatterable minefields

b. Direct fire

To update the location of the Red force in the direct fire region, equation (2.16) is used to calculate the Red force speed during each time step. The equation shows that unit speed decreases as the range between opposing forces decreases, but gets no smaller than a specified minimum speed (S_{min}).

$$S_{new} = S_{old} \times (1 - \frac{a_c}{a_0})^v + S_{\min} \qquad (2.16)$$

where

v : power factor, based on different weapon types
S_{new} : updated speed of attacking force
S_{old} : speed of attacking force for past time step
$S_{\min}$: minimum speed for the attacking force
a_c : current attrition coefficient
a_0 : maximum attrition coefficient

Equation (2.16) is portrayed graphically in Figure 9. Actual model results are discussed in Chapter 3.

4. Advanced model

To obtain the required data for analysis, the basic model is expanded. The advanced model uses the basic model as a submodel and produces two output matrices (see Figure 11). The upper portion of the figure is the output matrix of four selected MOE values for use in Table 2, which is a 4 by 8 matrix for the Red and Blue options for each MOE. MOE-1 through MOE-4 represent Red casualties, Blue survivors, duration of battle, and Red to Blue casualty ratio, respectively. The lower part of the figure contains utility values for three different utility functions (Linear, Squared, and Square Root) versus Blue options for MOE-2 values (Blue survivors). The utility values are based upon the way the Blue commander weighs the Red options. The characteristics of each utility function and weighted utility values are discussed in Chapter 3.

In the advanced model, the user can decide whether the attacking Red forces through Avenue-2 are equally divided at node-14 (BATTLE2 case), or continue to attack to only one of the Blue positions (BATTLE1 case). The computer program of the advanced model is listed in Appendix D. The flow chart of the advanced model is in Figure 10, and the following definitions apply:

BATTLE1 = basic model which has three avenues of approach (Red force on Avenue-2 will choose only one of two objectives to attack).

BATTLE2 = basic model which starts with three avenues of approach but divides into four because the Red force on Avenue-2 will be divided equally at node-14 and attacks toward each objective, respectively.

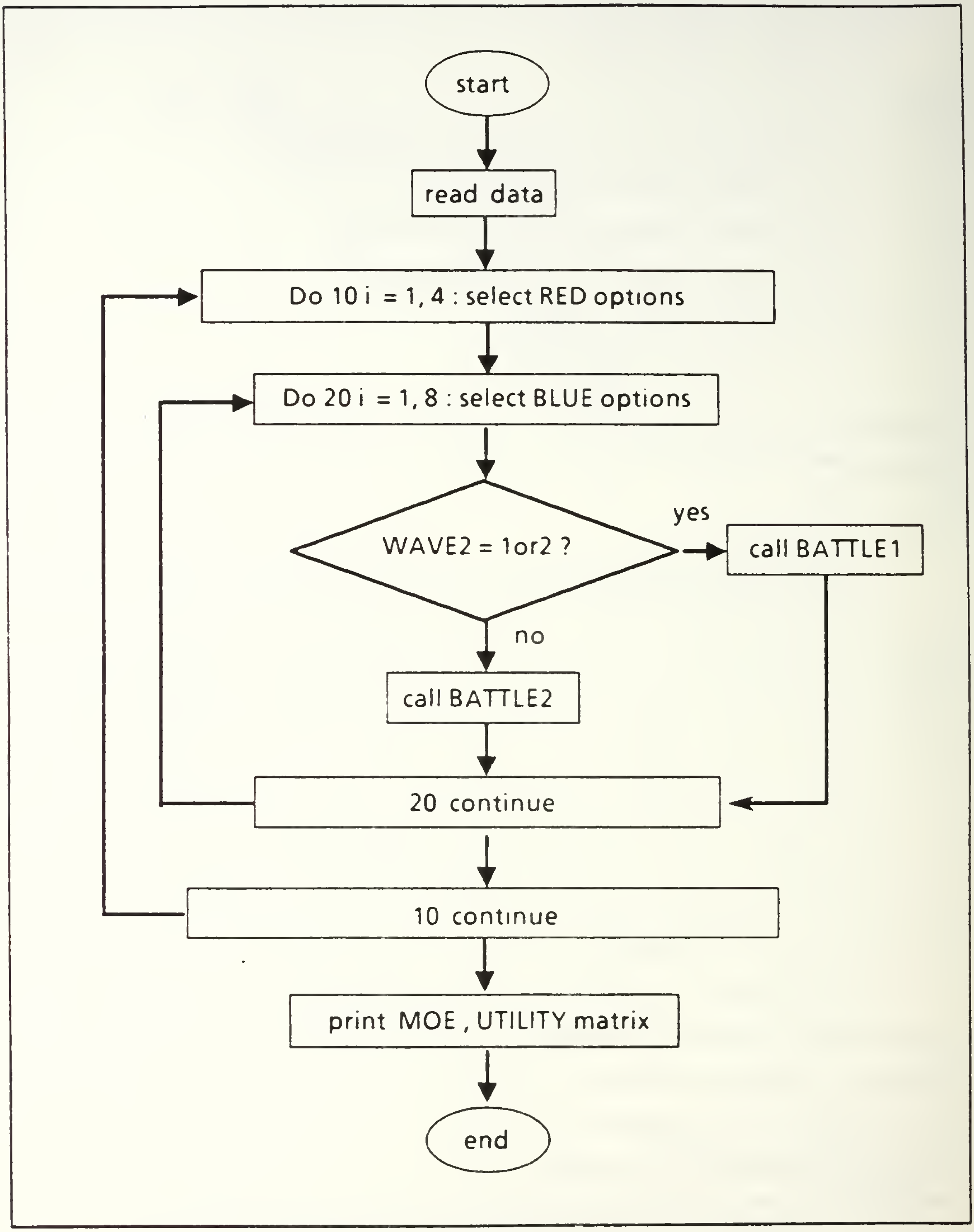
start
read data
Do 10 i = 1, 4 : select RED options
Do 20 i = 1, 8 : select BLUE options
WAVE2 = 1or2 ?
yes
call BATTLE1
no
call BATTLE2
20 continue
10 continue
print MOE , UTILITY matrix
end

Figure 10. Flow chart of the advanced model

WAVE2 = numeric value (1, 2, or 12) which is supposed to be given by the model user ; if WAVE2 = 1, it will be a BATTLE1 case, and all Red forces on Avenue-2 attack to node-28 ; if WAVE2 = 2, it will also be a BATTLE1 case, but all Red forces on Avenue-2 attack to node-27 ; if WAVE2 = 12, it will be a BATTLE2 case.

These outputs will be analyzed in more detail in the next chapter. The example output of the advanced model is shown in Figure 11.

```
<< MOE VALUES BASED ON THE RED AND BLUE OPTIONS >>
----------------------------------------------------
    RED    1        2        3        4
BLUE
----------------------------------------------------
     1    759.6    802.3    949.2    828.5     <=== MOE-1
     1    349.9    278.1    219.9    230.1     <=== MOE-2
     1    215.0    225.0    290.0    229.0     <=== MOE-3
     1      3.80     2.95     2.88     2.59    <=== MOE-4
     2    795.2    751.7    951.3    783.0
     2    321.1    307.6    220.0    268.9
     2    224.0    225.0    290.0    229.0
     2      3.47     3.10     2.88     2.79
     3    786.9    795.4    967.3    817.1
     3    321.7    278.4    241.6    230.4
     3    223.0    225.0    283.0    229.0
     3      3.45     2.93     3.14     2.56
     4    771.0    752.0    923.0    787.0
     4    345.5    297.3    224.4    271.0
     4    215.0    225.0    280.0    229.0
     4      3.77     2.98     2.83     2.82
     5    768.6    747.8    810.1    733.7
     5    336.3    298.7    297.5    251.1
     5    215.0    225.0    290.0    229.0
     5      3.60     2.98     3.21     2.45
     6    813.9    639.9    808.9    630.5
     6    316.5    346.3    297.9    305.0
     6    224.0    225.0    290.0    229.0
     6      3.49     3.14     3.21     2.57
     7    803.5    737.4    847.3    722.1
     7    305.7    299.1    307.1    251.4
     7    223.0    225.0    283.0    229.0
     7      3.29     2.94     3.49     2.42
     8    773.9    632.4    787.7    631.3
     8    345.5    342.3    300.4    308.0
     8    215.0    225.0    280.0    229.0
     8      3.79     3.05     3.16     2.61

    << WEIGHTED UTILITY VALUES USING MOE-2 >>
---------------------------------------------------
     LINEAR U(X)  SQUARED U(X)  SQUARE ROOT U(X)
---------------------------------------------------
   1    44.56         24.24           69.87
   2    48.47         29.19           73.32
   3    44.05         24.14           69.90
   4    48.10         28.14           72.67
   5    47.63         28.17           72.70
   6    61.69         37.05           77.92
   7    47.51         28.00           72.62
   8    62.09         36.87           77.86
```

Figure 11. The output of the advanced model

III. MODEL OUTPUT ANALYSIS

A. OVERVIEW

As mentioned in Chapter 1, the purpose of this thesis is to analyze the key variables of air-land combat models in high resolution and provide some analytical methodologies. This chapter focuses on several methods of analysis of model output while the following chapter explores various sensitivity analyses.

Since this model is sequenced by time steps, the user can easily visualize the battle situation as the battle progresses. For example, if the Blue force places a certain size minefield on a certain arc of the network terrain model, the output will show how the minefield affects the casualties and speed of the Red force. The next four figures (Figure 12-15) provide more displays of battle situations which occur on each avenue. Figures 12-15 are created based on sample output of the basic model in the previous chapter. In this battle case, the Red force is assumed to take option-2 (allocation of two battalions on Avenue-2, one battlion on Avenue-3, and no unit allocation on Avenue-1). The Blue force is assumed to employ option-2, which locates one company on position-1 (node-28) and two companies on position-2 (node-27), etc. (see O_{22} of Table 2 in Chapter 2).

Figure 12 shows how the Red and Blue force sizes are decreasing on each avenue. Note that the Red forces attacking on Avenue-22 are severely attrited and end up with approximately one third of the initial forces even though they were reinforced by a reserve company (150 infantrymen). The unit reinforcement is supposed to occur if the Red forces are less than the Blue forces after they are engaged in the direct fire battle. On Avenue-22 of Figure 12, Red on that avenue is reinforced at battle time 160 which appears to be the beginning of the direct fire battle. The Blue force lost more than half of the initial forces in combat on position-2. The approximate number of casualties caused by the indirect fire and ambush attack can also be observed. Note, in Figure 12, that the Red casualties on Avenue-22 are much more than those on the other avenues of approach. In other words, the intensity of the battle between Red forces on Avenue-22 and Blue force on position-2 was very high. There are no forces on Avenue-1 because the Red force did not allocate any forces there.

Figure 13 depicts the size or proportion of Red casualties in relation to each weapon employed by the Blue force, such as indirect fire, mines, and direct fire. For example,

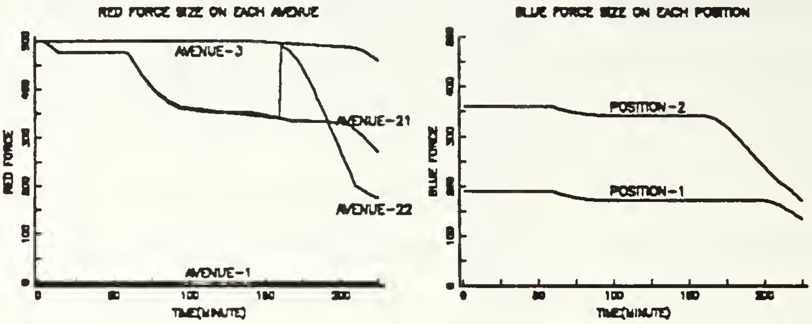

Figure 12. Red and Blue force sizes over time

on Avenue-22, a high proportion of the Red casualties were due to direct fire. Another item depicted is that the time when the Red force engaged in direct fire is based on the slope of the curve (i.e., the point that the slope of curve changes abruptly). An ambush attack occurred from approximately 55 to 90 on the battle clock (for 35 minutes) on Avenue-2 (actually this happened before the Red was divided onto Avenue-21 and Avenue-22 at node-14). The Red force on Avenue-21 entered the direct fire region at about 205 battle clock time, and at about 160 on Avenue-22, and at about 210 on Avenue-3. So, after 210 minutes, the Blue position-2 started to be threatened from two directions which were from Avenue-22 and Avenue-3. Note, even though the range of Avenue-21 (9.45Km : initial distance between Red and Blue force when the battle clock equaled 0) was much shorter than that of Avenue-3 (13.55Km), the Red forces on Avenue-21 and Avenue-3 were engaged in direct fire with the Blue force for a shorter period of time (between 205 and 210 minutes). That was because the Red forces on Avenue-21 were attrited more by Blue forces and their obstacles than those on Avenue-3.

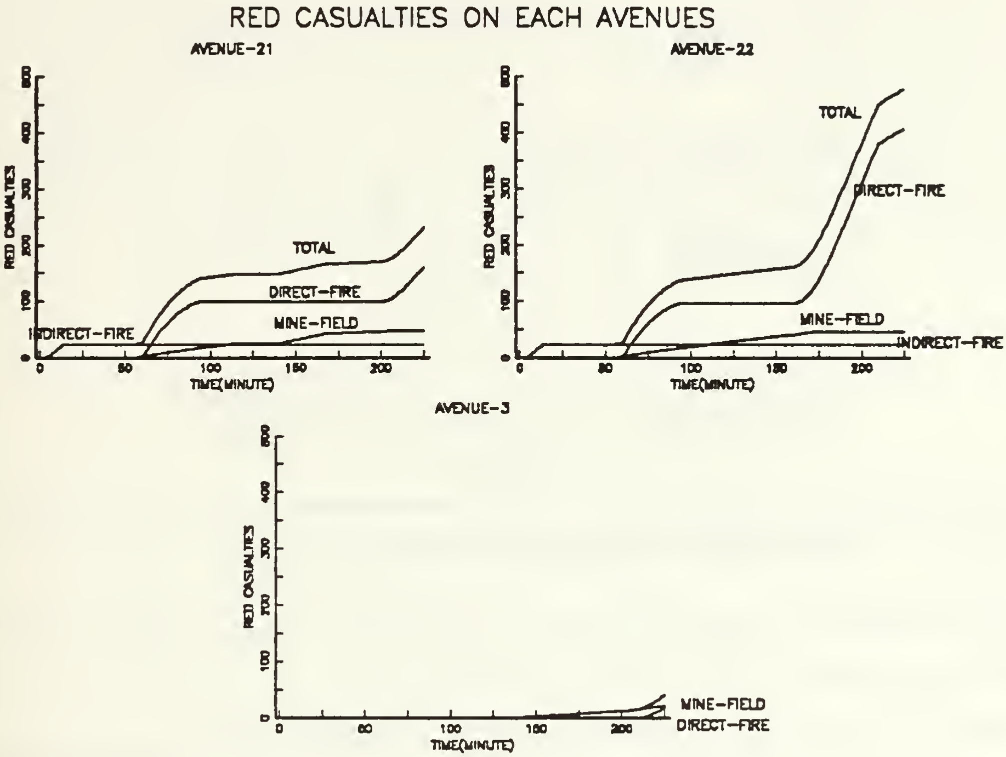

Figure 13. The Red casualties by different types of Blue weapons

The Blue commander may want to know where the Red forces are at certain times and the distance from which they are attacking. Figure 14 shows not only when the battle terminates but also who reached one of the Blue positions first. The Red force from Avenue-22 took the Blue position first in this battle case. In Figure 14, the slope of each curve represents the speed of the Red forces. For example, Avenue-3 has a constant speed from 0 to 130 battle clock time which means there is no attrition during that time, and Avenue-21 and Avenue-22 have very small slopes (low speed) during an ambush attack by Blue forces (from 55 to 90 battle clock time).

The speed of Red force is another important factor which can cause different Blue responses. Sometimes, the Blue forces need to know when the Red forces will reach their

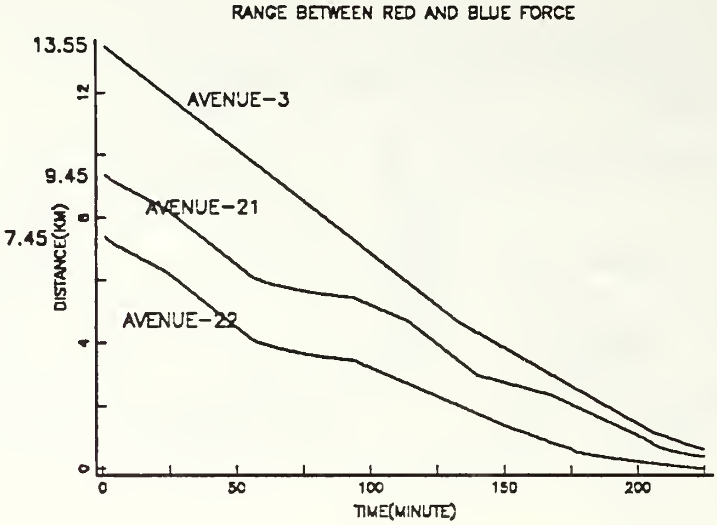

Figure 14. Distance between Red and Blue forces over time.

positions in order to prepare and decide on an effective course of action. The average speed of the attacker can be calculated from Figure 14.

Figure 15 also shows how fast the Red force moves and how their maneuverability is reduced by indirect fire, minefields, and the direct fire of the Blue force on each avenue. In the direct fire region, the Red forces are forced to slow their movement depicted by exponential shaped curve. Note how the curve changes during the ambush battle (at 55-90 battle clock).

B. MEASURES OF EFFECTIVENESS (MOES)

After considering the battle situations, four MOE values were selected to estimate how they changed in each of the time steps. The four MOEs are as follows:

- MOE-1 : number of Red casualties
- MOE-2 : number of Blue survivors
- MOE-3 : duration of battle
- MOE-4 : ratio of Red and Blue casualties (Loss exchange rates)

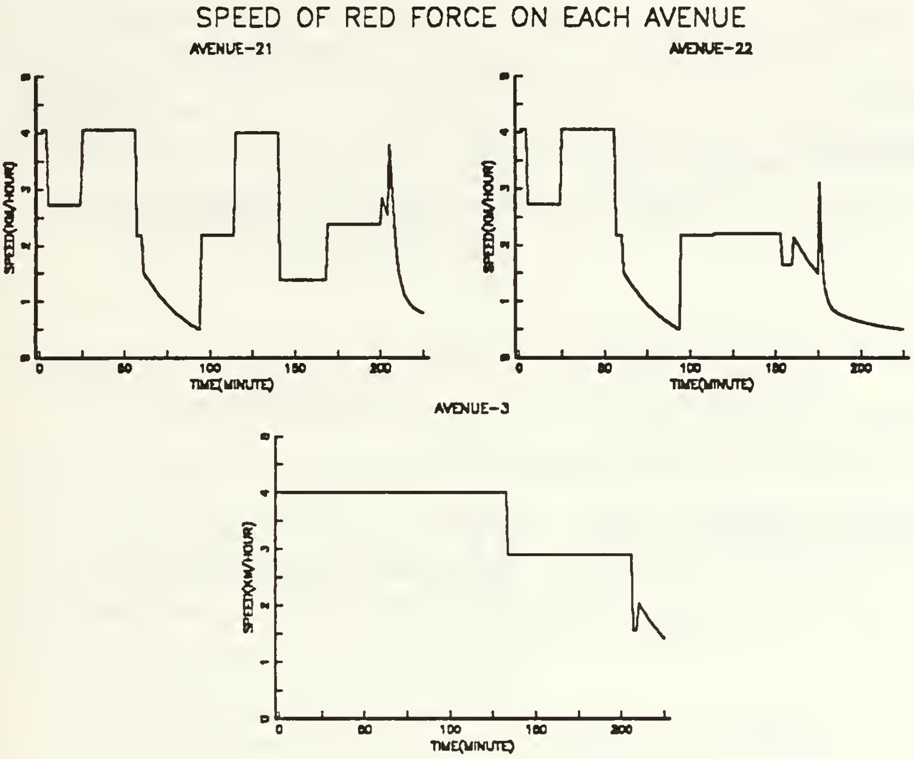

Figure 15. Speed of Red force on each avenue over time.

Larger MOE values are better for the Blue forces in all cases. The characteristics of all the MOEs' for this scenario are shown on Figure 16. For the particular option of Red and Blue, refer to Table 2 in Chapter 2.

For MOE-1, if the Red chose option-2, then the Blue force should select option-1, because the Blue force wants to maximize Red casualties (MOE-1). Blue has no large differences among its options for Red option-1. Note that Red options 2 and 4 show approximately the same tendency and this also happens for MOE-3. This implies that there is some relation between MOE-1 and MOE-3. In other words, Red casualties depend on how long the battle lasts.

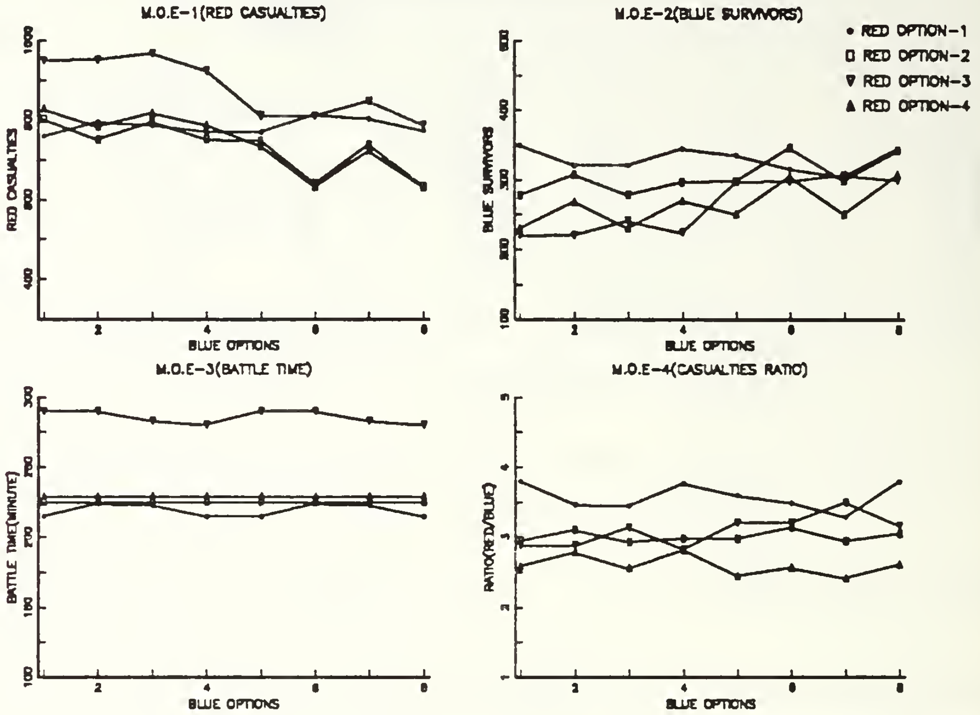

Figure 16. The MOE values for each options of Red and Blue (BATTLE2)

For MOE-2, the Blue forces are affected by the Red options in Blue option 1 through 5 but they are not severely affected in Blue option 6, 7, and 8. Note that Red option 2 and 4 of MOE-2 show almost reverse trends against those of MOE-1. This implies that the Red casualties have a negative correlation with the Blue survivors which agrees with the theoretical battle concept.

For MOE-3, Red option-3 has a longer battle time than any other options. The reason this occurs is that Red's main forces (two battalions) attack to the Blue positions over the Avenue-3 which is the longest among the three major avenues of approach. If the Red forces choose option 2 or 4, MOE-3 has constant values of 225 and 229, respectively. In other words, when the Red force allocates more than two units (battalions) on Avenue-2, the duration of battle will be same regardless of Blue's options.

MOE-4 seems to have some relationship with MOE-2, but the relationship is not entirely clear except for the Red option-1. It would require more analysis to verify the relationship between them such as a coefficient of correlation (ρ).

To summarize the MOEs, it is difficult to pick the best option which is the most benefitial for all MOEs for the Blue force. The course of action is strongly based on how Blue's decision maker wants to drive the battle according to his tactical courses of action.

C. COMPARISON BETWEEN BATTLE1 AND BATTLE2

This section will discuss differences between the results of BATTLE1 and BATTLE2. BATTLE1 has two approaches which the Red force can take on Avenue-2. So, in total, three battle types are compared. For a description of BATTLE1 and BATTLE2, refer to the last part of Chapter 2. The output of BATTLE1 came from the same battle which was discussed in Chapter 2 (Red's second option with Blue's second option). The differences are given in Table 4.

Table 4. COMPARISON OF MOES BETWEEN BATTLE1 AND BATTLE2

value names	BATTLE1		BATTLE2
	with Avenue-21	with Avenue-22	
MOE-1	763.3	609.3	751.7
MOE-2	158.6	242.8	307.6
MOE-3	264.0	228.0	225.0
MOE-4	1.95	1.98	3.10
Who reaches Where first?	Red on Avenue-3 to Node 27	Red on Avenue-22 to Node 27	Red on Avenue-22 to Node 27

From the Red force's viewpoint, it is better to choose Avenue-22 over Avenue-21 based on Red casualties (MOE-1) and duration of battle (MOE-3) since $609.3 < 763.3$ and $228 < 264$ [Note, the smaller MOE values is better for the Red force]. Compared with BATTLE2, if the Red force chooses Avenue-22 in BATTLE1, it can reduce its casualties and kill more Blue forces, even though the duration of battle increases by three minutes. The Red Blue casualty ratio (MOE-4) is indifferent as to whether the Red force chooses Avenue-21 or Avenue-22 in BATTLE1 (1.95 and 1.98). In BATTLE2, MOE-4 is much larger.

When the Red force chooses Avenue-21 in BATTLE1, the duration of battle increases to its greatest value, because the Red forces attacking through the longest path (Avenue-3) reached the Blue position (node-27) first and battle was terminated. From Blue's viewpoint, if the Blue force attempts to prolong the battle, it will attempt to channelize Red forces on Avenue-2 into Avenue-21 (because the duration of battle for BATTLE1 with Avenue-21 is the highest; 264 minutes in Table 4). Installing more mines and obstacles or conducting ambushes on Avenue-2 should be considered by the Blue force. As shown in Figure 17, Blue is at a disadvantage if Red chooses Avenue-22 in BATTLE1 (i.e., the best way for Red). Since Figure 17 was drawn with MOE ratios based on BATTLE2 battle type, it clearly shows the relative proportion of changes among the three battle types. Figure 17 also shows that the attacking force usually has the advantage in concentrating its forces on one objective, which is a well-known tactical concept of war.

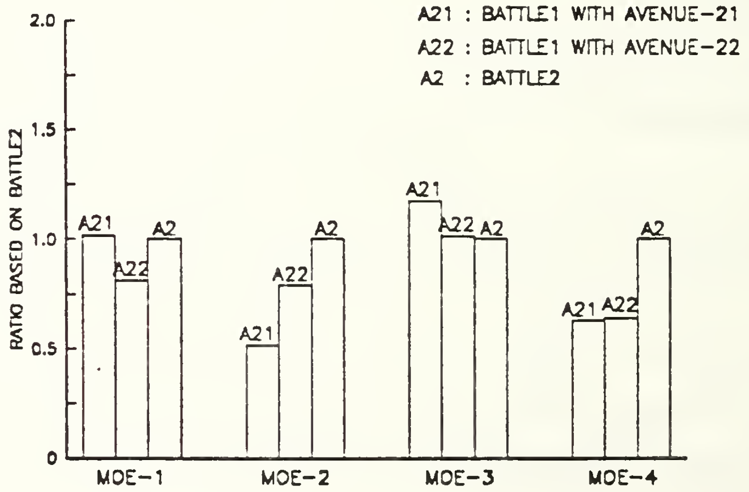

Figure 17. Ratio of MOEs in BATTLE1 types based on BATTLE2 type.

Figure 18 describes how all the battle case MOE's change when the Red forces that are on Avenue-2 choose Avenue-21. Compared with BATTLE2 (Figure 16), Red casualties (MOE-1) and the ratio of Red to Blue casualties (MOE-4) are relatively small, and

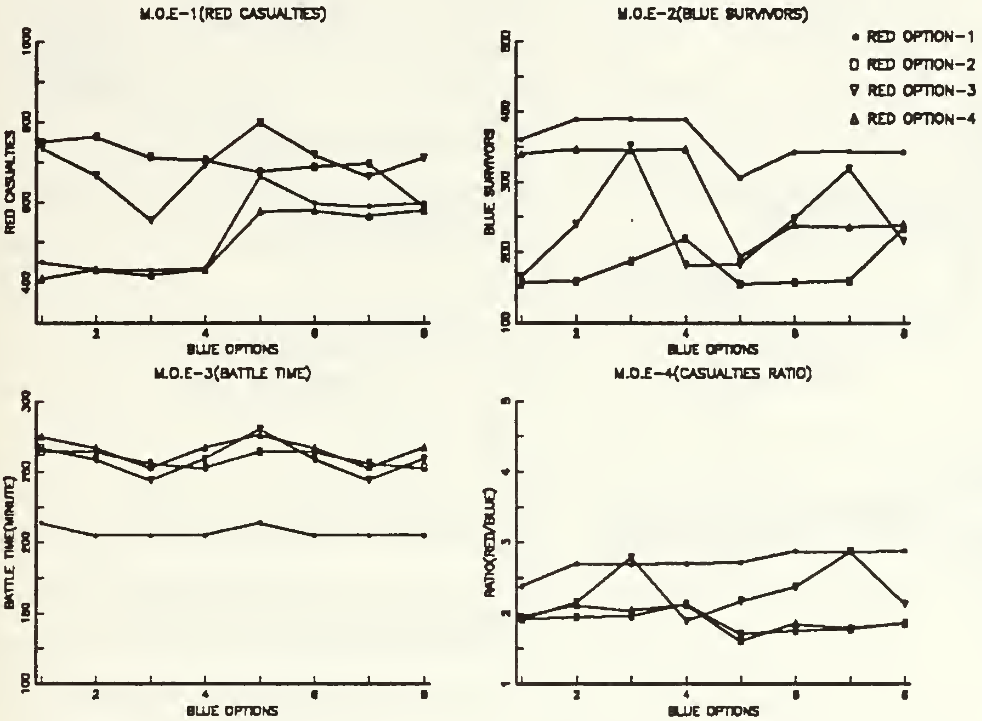

Figure 18. MOEs for each options of Red and Blue (BATTLE1 with Avenue-21)

the variance of Blue survivors (MOE-2) based on the Red options is large. Generally, the duration of battle (MOE-3) increases in BATTLE1 on Avenue-21, though Red casualties decrease (i.e., rate of killing per time is decreased). This fact implies that the number of units (infantrymen) engaging in direct fire in BATTLE1 on Avenue-21 is smaller than that of BATTLE2. In other words, the troop density in BATTLE1 on Avenue-21 is small.

Figure 19 shows how all battle MOEs change when Red forces on Avenue-2 choose Avenue-22. In this battle, Red casualties (MOE-1) are the smallest among all three battle types. For MOE-1, there is a interesting phenomena which is that Red option-1 case has a reverse shape from all other Red option cases with respect to the Blue

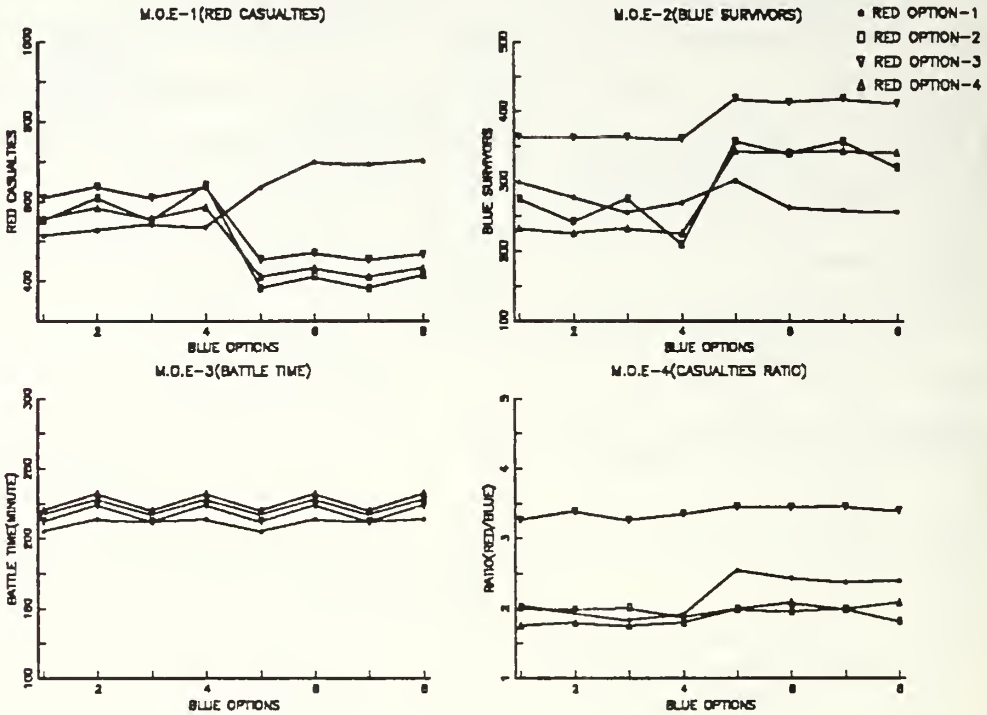

Figure 19. MOEs for each options of Red and Blue (BATTLE1 with Avenue-22)

options. For the duration of battle (MOE-3), there are no large differences among the Red options. All MOE-3 values are between 205 and 235 minutes of battle time, because all 32 battle cases (four Red options with eight Blue options) are terminated by the Red forces on Avenue-22. Therefore, this deterministic model shows that the Blue force needs other courses of actions in order to hold its potions for more than 4 hours. Blue survivors (MOE-2) and ratio of Red to Blue casualties (MOE-4), values are relatively constant for each Red option based on Blue options.

In summary, the assumption that the Red force will choose BATTLE1 on Avenue-22 forces Blue to consider other courses of action against Red.

D. UTILITY THEORY

1. General

Individuals (or Decision Makers) frequently must choose among alternatives that differ, among other things, in the degree of risk to which the individual will be subjected. The clearest examples are provided by insurance and gambling. An individual who buys fire insurance on a house he owns is acceping the certain loss of a small sum (the insurance premium) in preference to the combination of a small chance of a much larger loss (the value of the house) and a large chance of no loss. That is, he is choosing certainty in preference to uncertainty. An individual who buys a lottery ticket is subjecting himself to a large chance of losing a small amount (the price of lottery ticket) plus a small chance of winning a large amount (a prize) in preference to avoiding both risks. He is choosing uncertainty in preference to certainty. [Ref. 6 : p. 234].

In order to develop a means to rank probability distributions we must resort to the theory of "Utility". This provides a consistent way in which to combine different figures of merits or sub-MOE's, subjective and judgemental factors, and probabilistic aspects of outcomes (i.e., risk factors) into an overall MOE appropriate for the level in the hierarchy in which each decision maker must function. [Ref. 7 : p. 9].

2. Application

Three different utility functions are proposed to compare each battle situation by using MOE-2, which is the number of Blue survivors. These utility functions are represented as linear, squared, and square root, and are depicted in Figure 20. The utility curves reflect the decision maker's judgement.

a. Linear Utility

Using the fact that the utility functions are arbitrary up to a positive linear transformation, for convenience we define:

$$U(550 \text{ survivors, i.e., no losses}) = 100$$

$$U(0 \text{ survivors, i.e., all losses}) = 0$$

As a Blue decision maker, it is assumed that if the number of survivors decrease to less than 340, which is the size of two companies (i.e., if they lost one company out of three), the utility value of the Blue force drops with a 10 percent step change. The appropriate function for linear utility is given by equation (3.1).

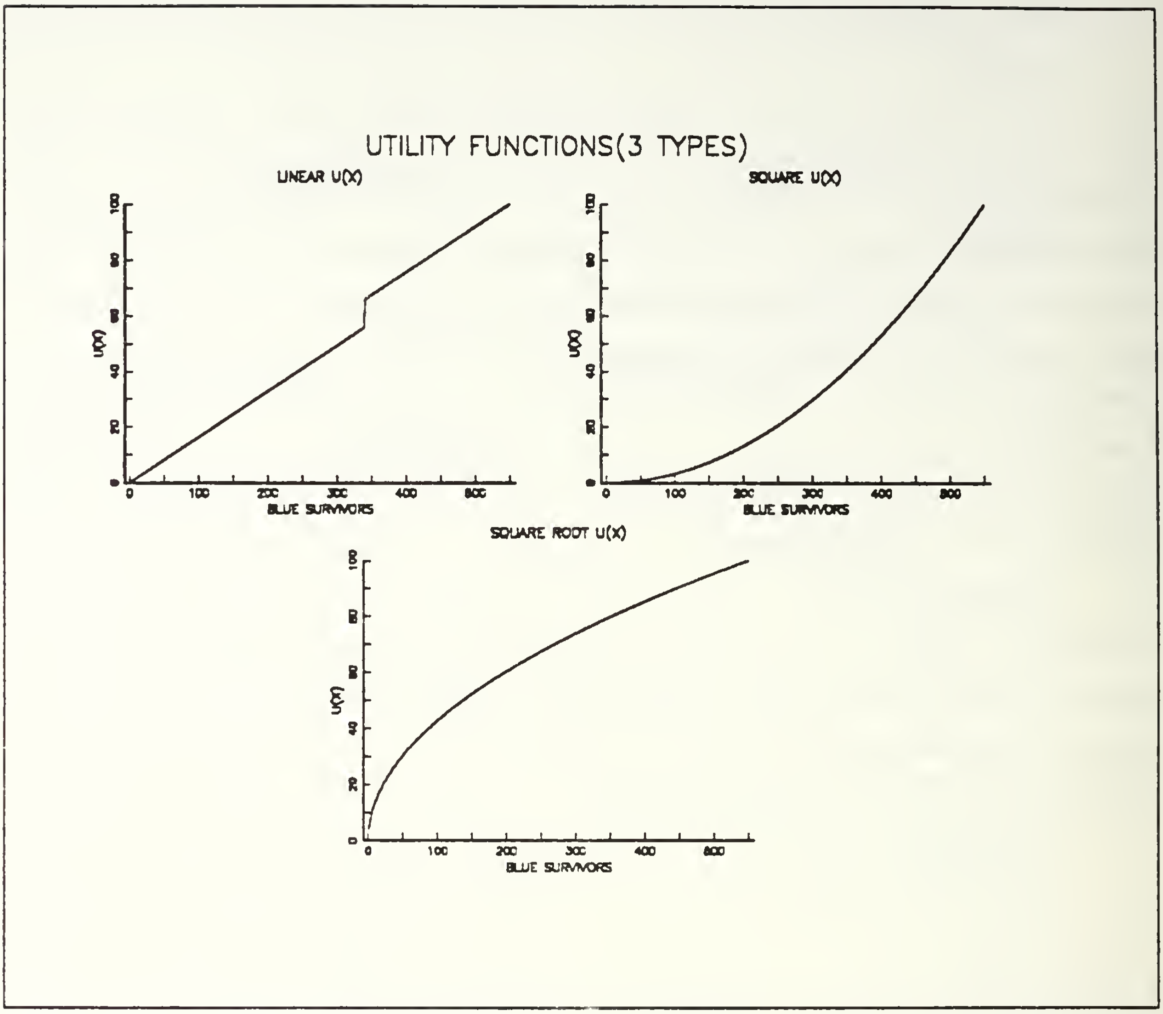

Figure 20. Three different utility distribution functions.

$$U(x) = \begin{cases} \frac{9}{55}x & , \quad x < 340 \\ \frac{9}{55}x + 10, & x \geq 340 \\ 0 & , \quad \textit{otherwise} \end{cases} \qquad (3.1)$$

b. Squared Utility

This is concave upward function which will result in a ***risk prefering*** decision. The appropriate function for squared utility is given by equation (3.2).

$$U(x) = \begin{cases} \frac{1}{3025} x^2 & , \quad x > 0 \\ 0 & , \quad \textit{otherwise} \end{cases} \tag{3.2}$$

*c. **Square root Utility***

This utility curve is concave downward. It generally represent the ***risk averse*** case; most individuals and organizations generally are risk averse with respect to most decisions. The appropriate function for square root utility is given by equation (3.3).

$$U(x) = \begin{cases} 4.264 \sqrt{x} & , \quad x > 0 \\ 0 & , \quad \textit{otherwise} \end{cases} \tag{3.3}$$

If it is assumed that Red's options are weighted as w_1, w_2, w_3, w_4 for each option. then weighted utility values can be calculated by equation (3.4).

$$U(x) = w_1 \, U_1(x) + w_2 \, U_2(x) + w_3 \, U_3(x) + w_4 \, U_4(x) \tag{3.4}$$

where

U(x) : weighted utility value
w_i : proportion of weight for i-th Red option. $0 \leq w_i \leq 1$ i = 1,2,3,4
$U_i(x)$: utility value of i-th Red option. i = 1,2,3,4

As an example. with given values of w_i (0.05, 0.70, 0.05, 0.20), the weighted utility values for each function are shown in Figure 21. This figure represent the characteristics of MOE-2 for the Red option-2 well, because the Blue decision maker puts large weight (0.70) on the Red option-2 (see Figure 16 for MOE-2). Note, in the Linear Utility case, Blue options 6 and 8 are emphasized because their MOE-2 values are greater than 340 (i.e., Blue survives with more than two companies) while the others are not.

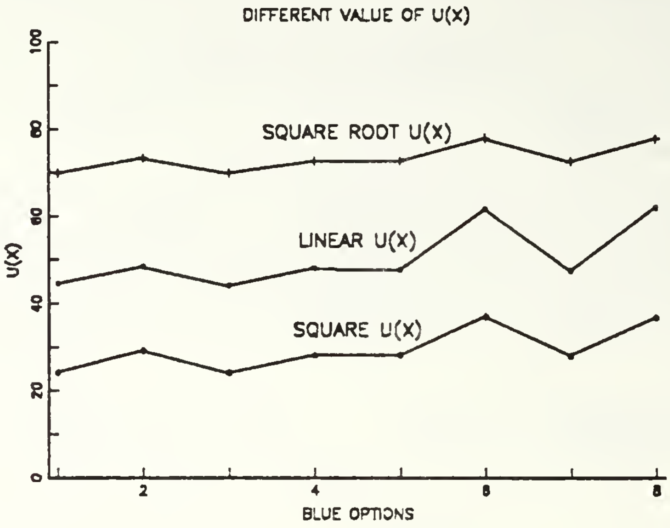

Figure 21. Weighted utility values for each function.

E. GAME THEORY

1. General

In game theory, the word "strategy" has a very definite meaning, namely, "a complete rule for decision making". [Ref. 8 : p. 2]. By the assumptions, all initial MOE values consist of a 4 by 8 matrix and the values for each MOE matrix come from the output of the advanced model (Figure 11 in Chapter 2). A strategy is a particular Blue option paired with a particular Red option. In order to study the characteristic properties of games of strategy and find an optimal strategy for the two players (Red and Blue), the 4 by 8 "Rectangular Game" is utilized. Two theorems are also used to compute the ***value of the game***. [Ref. 9 : p. 34 and 39].

Theorem 1. : Let

$$A = \begin{bmatrix} a_{11} & \cdots\cdots & a_{1n} \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ a_{m1} & \cdots\cdots & a_{mn} \end{bmatrix}$$

be any matrix, with m rows n columns, and let the expectation function E(X,Y), for any $X = ||x_1 \ldots x_m||$ and $Y = ||y_1 \ldots y_n||$ that are members of S_m and S_n, respectively, be defined as follows:

$$E(X,Y) = \sum_{i=1}^{m} \sum_{j=1}^{n} a_{ij} x_i y_j \tag{3.5}$$

Then the expressions

$$\max_{X \in S_m} \min_{Y \in S_n} E(X,Y) \tag{3.6}$$

and

$$\min_{Y \in S_n} \max_{X \in S_m} E(X,Y) \tag{3.7}$$

exist and are equal. Where;

S_m : close subset of whole space (E_m) which have elements, $x_1, \ldots, x_m$.

S_n : close subset of whole space (E_n) which have elements, $y_1, \ldots, y_n$.

Theorem 2. : Let E be the expectation function for an $m \times n$ rectangular game, let v be a real number, and let X^* and Y^* be members of S_m and S_n, respectively. Then a necessary and sufficient condition that v be the value of the game and that X^* and Y^* be optimal strategies for P_1 and P_2, respectively, is that, for $1 \leq i \leq m$ *and* $1 \leq j \leq n$.

$$E(i,Y^*) \leq v \leq E(X^*,j).$$

2. Application

a. *MOE-1 (Red casualties)*

The initial 4 by 8 matrix is reduced to a 3 by 5 matrix which results in a Mixed Strategy[1] solution (see Figure 22). The relations of dominance are as follows:

Column 3 dominate column 4 = = = > eliminate column 3

Row 3 dominate row 4 = = = > eliminate row 4

---

[1] Rectangular game whose matrix has no saddle point, that is, Red could determine optimal way with probabilities $P_1, P_2, \ldots, P_c$ for each column of matrix, and Blue could determine optimal way with probabilities $P_1, P_2, \ldots, P_r$ for each row of matrix. For more explanation in detail, refer [Ref. 9 : p. 21].

Row 3 dominate row 5 = = = > eliminate row 5

Row 7 dominate row 8 = = = > eliminate row 8

By Theorem 2, the reduced matrix suffices to find numbers x_1, x_2, x_4, y_1, y_2, y_3, y_6, y_7, and v which satisfy the following conditions:

$$x_1 + x_2 + x_4 = 1$$

$$y_1 + y_2 + y_3 + y_6 + y_7 = 1$$

$$0 \leq x_i,\ y_j \leq 1 \qquad i = 1,2,4 \text{ and } j = 1,2,3,6,7$$

$$759.6x_1 + 802.3x_2 + 828.5x_4 \leq v$$

$$795.2x_1 + 751.7x_2 + 783.0x_4 \leq v$$

$$786.9x_1 + 795.4x_2 + 817.1x_4 \leq v$$

$$813.9x_1 + 639.9x_2 + 630.5x_4 \leq v$$

$$803.5x_1 + 737.4x_2 + 722.1x_4 \leq v$$

$$759.6y_1 + 795.2y_2 + 786.9y_4 + 813.9y_6 + 803.5y_7 \geq v$$

$$802.3y_1 + 751.7y_2 + 795.4y_3 + 639.9y_6 + 737.4y_7 \geq v$$

$$828.5y_1 + 783.0y_2 + 817.1y_3 + 630.5y_6 + 722.1y_7 \geq v$$

From Theorem 1, we know that there exists a solution to the system. These conditions were solved by using Linear, INteractive, Discrete Optimizer (LINDO) [Ref. 10] which utilizes a Linear Program to find the optimum solution (see Figure 23 for the equations and results). In this solution, the objective equation is set to find a maximum value of v. If the objective equation is set to find a minimum value of v, the result will be the same. Note, that if there is a negative element in the matrix of Mixed Strategy, the Linear Program method can not be used.

Based on the solution in Figure 23, an optimal way for Red to play this game is to choose options 1, 2, and 4 with respective probabilities 0, 0.78, and 0.22; and an optimal way for Blue to play is to choose options 1, 2, 3, 6, and 7 with respective probabilities 0, 0, 0.89, 0, and 0.11. The ***value of the game*** is 788.8; i.e., Red can play in such a way as to make sure of not losing more than 788.8 Red casualties, and Blue can play in such a way as to make certain that Red will lose at least 788.8.

```
<< Initial matrix (4 x 8) >>
            1        2        3        4
    1     759.6    802.3    949.2    828.5
    2     795.2    751.7    951.3    783.0
    3     786.9    795.4    967.3    817.1
    4     771.0    752.0    923.0    787.0
    5     768.6    747.8    810.1    733.7
    6     813.9    639.9    808.9    630.5
    7     803.5    737.4    847.3    722.1
    8     773.9    632.4    787.7    631.3

<< Reduced matrix (3 x 5) >>
            1        2        4
    1     759.6    802.3    828.5
    2     795.2    751.7    783.0
    3     786.9    795.4    817.1
    6     813.9    639.9    630.5
    7     803.5    737.4    722.1
```

Figure 22. Initial matrix and reduced matrix for MOE-1

b. MOE-2 (Blue survivors)

A similar method as the MOE-1 case was used for MOE-2. After eliminating the redundant rows and columns by relations of dominance, the following 2 by 2 Mixed Strategy matrix is left.

Blue Red	3	4
7	307.1	251.4
8	300.4	308.0

This implies that the Red favors its option 3 and 4, and the Blue favors its option 7 and 8. Since a 2 by 2 matrix is simple to solve, familiar methods of elementary algebra were used. An optimal startegy for Red is ||0.89, 0.11||, an optimal strategy for Blue is ||0.12, 0.88||; and the ***value of the game*** is 301.2 Blue survivors. So, not more than two Blue companies (340 infantry men) may survive during the battle.

c. MOE-3 and MOE-4

MOE-3 and MOE-4 do not have a mixed strategy, but have a unique strategy which can be easily found by inspection. For MOE-3 (duration of battle), the Red option-1 is dominated by its option 2,3, and 4 so that the Red will choose its option-1. Thus, an optimal strategy is that Red choose its option-1 with probability 1

```
  << EQUATIONS FOR LINEAR PROGRAM >>

MAX     V
SUBJECT TO
    2)   X1 + X2 + X4 = 1
    3)   Y1 + Y2 + Y3 + Y6 + Y7 = 1
    4) - V + 759.6 X1 + 802.3 X2 + 828.5 X4 <= 0
    5) - V + 795.2 X1 + 751.7 X2 + 783.0 X4 <= 0
    6) - V + 786.9 X1 + 795.4 X2 + 817.1 X4 <= 0
    7) - V + 813.9 X1 + 639.9 X2 + 630.5 X4 <= 0
    8) - V + 803.5 X1 + 737.4 X2 + 722.1 X4 <= 0
    9) - V + 759.6 Y1 + 795.2 Y2 + 786.9 Y3 + 813.9 Y6 + 803.5 Y7 >= 0
   10) - V + 802.3 Y1 + 751.7 Y2 + 795.4 Y3 + 639.9 Y6 + 737.4 Y7 >= 0
   11) - V + 828.5 Y1 + 783.0 Y2 + 817.1 Y3 + 630.5 Y6 + 722.1 Y7 >= 0
END



  << OUTPUT OF LINEAR PROGRAM >>

    LP OPTIMUM FOUND  AT STEP    12

         OBJECTIVE FUNCTION VALUE

 1)        788.791260

VARIABLE         VALUE          REDUCED COST
       V       788.791260          0.0
      X1         0.777479          0.0
      X2         0.222521          0.0
      X4         0.0               0.0
      Y1         0.0              19.689911
      Y2         0.0               3.271210
      Y3         0.886059          0.0
      Y6         0.0              13.610260
      Y7         0.113941          0.0
```

Figure 23. Solution for Value of the Game (MOE-1)

and Blue choose its option-6 with probability 1. The ***value of the game*** is 224 minutes which means that the Blue forces can hold their positions at least 3 hours and 44 minutes. From a tactical viewpoint, the Blue forces have to be reinforced before 224 minutes of battle time if Blue does not want to lose their positions.

For MOE-4 (ratio of Red and Blue casualties), the Red option-4 is dominated by its option 1, 2, and 3 so that the Red will choose its option-4 to minimize the Red/Blue casualty ratio. Thus, an optimal strategy is that Red choose its option-4 with probability 1 and Blue choose its option-4 with probability 1. The ***value of the game*** is 2.82 Red casualties per Blue casualty which means that one Blue force unit can kill 2.82 Red units in the battle.

F. USE OF UTILITY VS GAME THEORY FOR THE ANALYST

The choice of technique depends on how the analyst desires to view the enemy force. For the Utility approach, the ***states of nature*** , with appropriate probabilities, would be assigned by the analyst. If intelligence reports are available, these could be used to determine the most likely Red option (i.e., unit mix on various avenues).

For Game theory, we are assuming that both Red and Blue forces are using the same payoff matrix, and that Red and Blue are making strategy decisions according to the max(min) and min(max) criteria, respectively. In the analyses, Red is being treated as an intelligent player as opposed to ***states of nature***. Results from this analysis can be used to determine the frequency with which Red will choose his various options.

IV. SENSITIVITY ANALYSIS

A. GENERAL

The previous chapters have considered, using the deterministic model and its output, analysis based on a given scenario. In all cases, the analysis was based on a fixed force size and a given set of weapon parameters. This chapter examines the numerical sensitivity of the methodologies and the effect on the model output interpretation as it pertains to Red and Blue options. The Analysis of Variance (ANOVA) and Two Sample t-Test are applied to support the sensitivity analysis. Some introductory analytical techniques to evaluate countermeasures are also covered, and an example of model enrichment is considered.

The deterministic model developed in this thesis has used many parameters which may possibly be changed based on real battle situations. For example, attrition rate coefficients may be affected if Red uses "Smoke" while they attack, since smoke will restrict the firepower of opposing forces. This would also occur in the night battle case. If Red uses a "Mine-plow" when it traverses the minefield, attrition rate coefficients for mines should also be decreased. From the Blue force's viewpoint, installing more mines in the minefield or increasing the amount of indirect fire may be used as countermeasures against the Red force. These key parameters are varied in turn to determine their effects on outputs of the model. Those parameters which are shown to have little or no effect on the results may be treated as constants and the model simplified accordingly. Those showing large sensitivity should be examined in detail, since these will affect model performance to the greatest degree.

B. FORCE SIZE

The force size is one of the major factor to affect the battle output. In this section, the Blue forces are considered to be reinforced by one additional platoon (40 infantrymen). Two methods of reinforcement are compared with the basic battle case which has no reinforcement, and the basic battle also has Blue option-2 and Red option-2 (refered to as O_{22} of Table 2 in Chapter 2). These battle cases' results have been discussed in detail in Figure 12-15 in Chapter 3 as an example of the basic model output.

Figure 24 shows Red and Blue force sizes over time when the Blue ambush point is reinforced with one more platoon. Compared with Figure 12 in Chapter 3, the rate of

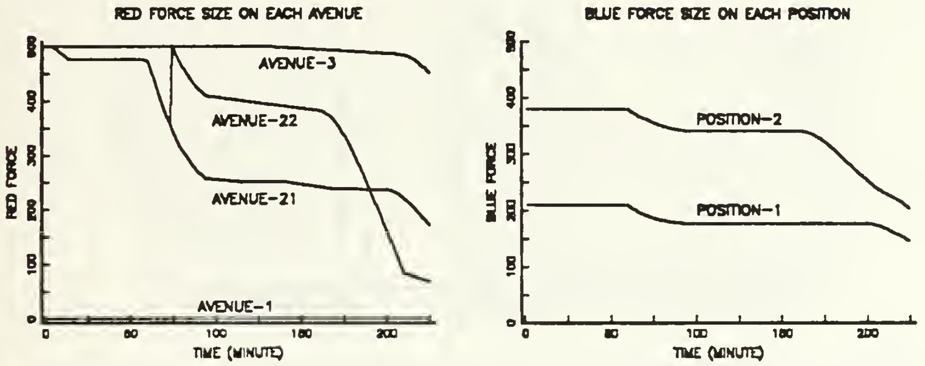

Figure 24. **Red and Blue force sizes over time when the Blue ambush point is reinforced.**

decreasing Red forces is very steep at the ambush battle region (for battle time 55-90 minutes). Since the Red force on Avenue-22 is reinforced during the ambush battle (about time 70), this implies that the Red force size on Avenue-22 is reduced to the same as that of the Blue force based on the model assumption (the unit reinforcement is supposed to occur if the Red forces are less than the Blue forces). The shape of the Blue force size curve looks similar compared with Figure 12 in Chapter 3 except that the slope of the curve during the ambush battle region is somewhat steeper than those in Figure 12.

Figure 25 provides significant information if the Blue commander wants to know the difference depending on whether he reinforces a given platoon at the ambush point or at the main forces areas on node 27 and 28. The Red casualties (MOE-1) are the highest when the ambush point is reinforced while there is no large difference with respect to the Blue survivors (MOE-2) between the two reinforcement methods (R1 and R2 in Figure

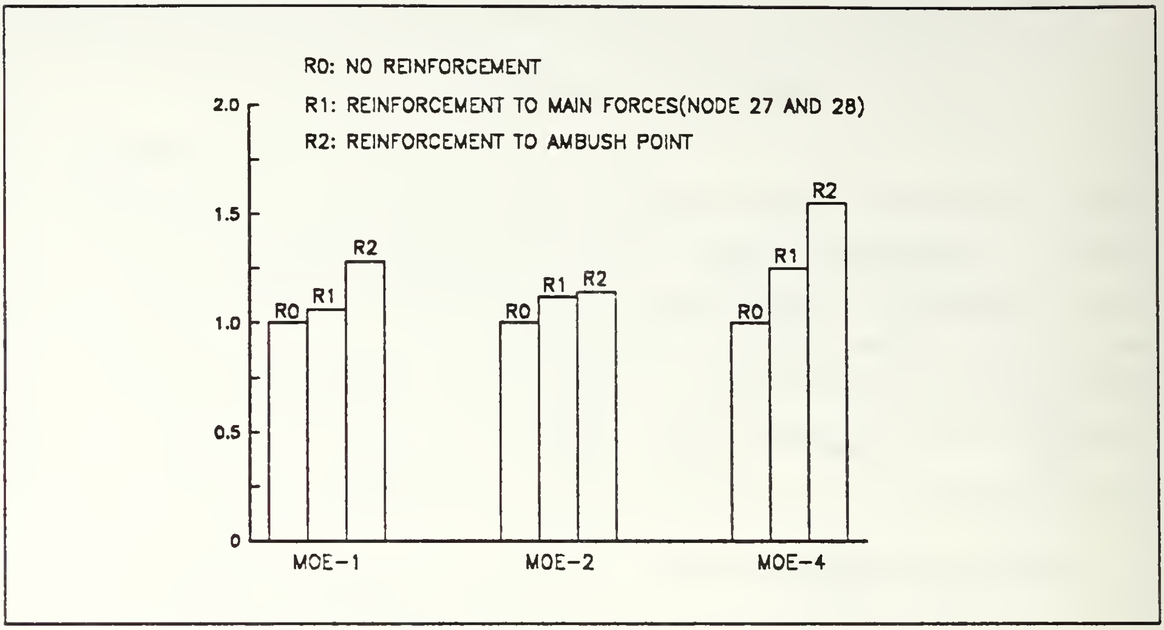

Figure 25. Comparison of MOEs when the Blue forces are reinforced.

25). The Red to Blue casualtiy ratio (MOE-4) linearly increases from the R0 to R2 case in Figure 25. Based on Figure 25, reinforcing a platoon at the ambush point appears to be a better course of action for the Blue commander. However, the following conditions should be considered before the final decision of whether a Blue platoon is reinforced at the main forces areas or ambush point.

- Availability of well-fortified battle space for one more platoon to fight at the ambush point.
- Probability of being detected by Red when Blue ambush force size is increased (i.e., the more forces there are, the easier they are to be detected).

C. ATTRITION RATE COEFFICIENTS

1. Sensitivity for attrition rate coefficients.

The attrition rate coefficients are another important factor in the deterministic model. The maximum attrition rate coefficients, which are given by equations (2.13) and (2.14) in Chapter 2, can be varied. The "a_0" in equation (2.13) is the maximum rate at which Red forces are attrited by Blue, or the number of Red forces lost per unit of time. The "b_0" in equation (2.14) is the maximum rate at which Blue forces are attrited by Red, or the number of Blue forces lost per unit of time.

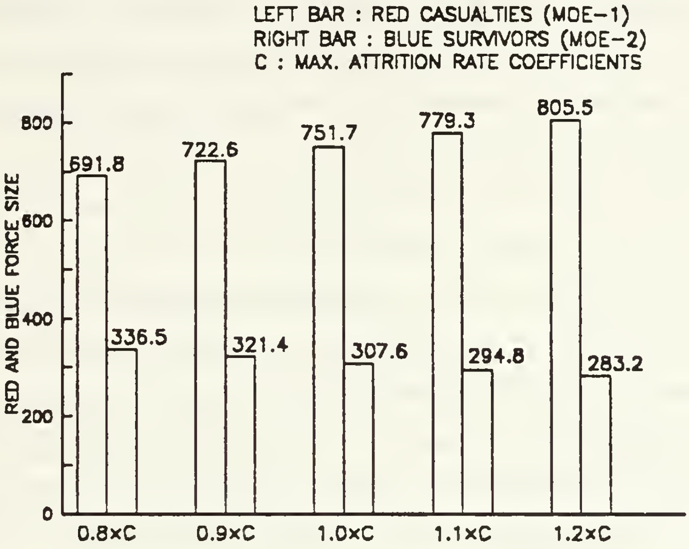

Figure 26. Change of MOE values based on different maximum attrition rate coefficients, a_0 and b_0

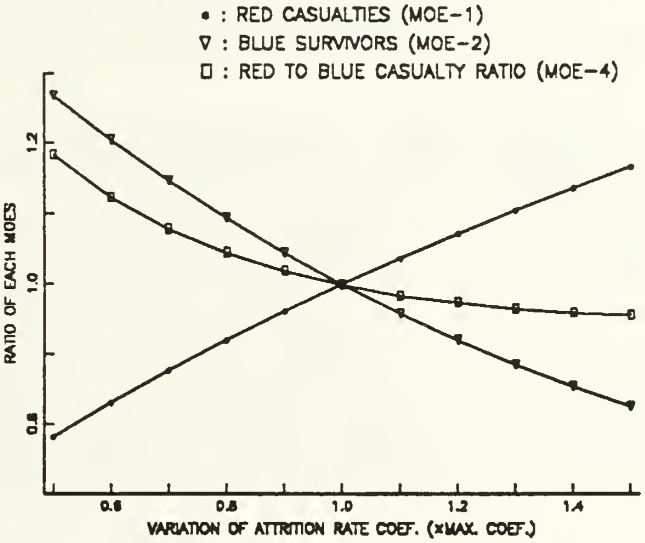

Figure 27. Ratio of change for MOE values based on different a_0 and b_0

Figure 26 is created with the MOE outputs of the basic model, which were discussed in a previous section, when both maximum attrition rate coefficients (a_0 and b_0) are changed to between 80% and 120% of original values in the basic model. Red casualties (MOE-1) increase linearly while Blue survivors (MOE-2) decrease linearly as a_0 and b_0 increase.

Figure 27 is the plotted ratio of MOE values with decreased or increased attriton rate coefficients to the basic model's MOE outputs with no changes of attrition rate coefficients. In this figure, unlike Figure 26, attrition rate coefficients (a_0 and b_0) are altered between 50% and 150% of original values. Figure 27 shows that the ratio of change for Red casualties (MOE-1) increases with a weak concave downward shape curve, which means that the rate of change for MOE-1 slightly decreases as the attrition rate coefficients get larger. The figure also depicts that the ratio of change for MOE-2 and MOE-4 decreases with a concave upward shape, which implies that the rates of change for Blue survivors (MOE-2) and Red to Blue casualty ratio (MOE-4) decrease as the attrition rate coefficients increases. In other words, as a_0 and b_0 increase, firepower effectiveness (or loss rate exchange) of the Blue force will be gradually reduced.

At this time, only one of the maxmum attrition rate coefficients, either a_0 or b_0, is changed and compared. The differences are given in Table 5. The numerical values in parentheses represent the percentage of MOE value change when compared with those of the basic case (no changes of attrition rate coefficients)

Table 5. SENSITIVITIES OF MOES FOR ATTRITION RATE COEFFICIENTS.

a_0	$0.9 \times a_0$	a_0	$1.1 \times a_0$
MOE-1	712.4 (94.8%)	751.7 (100%)	790.8 (105.2%)
MOE-2	302.4 (98.3%)	307.6 (100%)	313.0 (101.8%)
b_0	$1.1 \times b_0$	b_0	$0.9 \times b_0$
MOE-1	740.9 (98.6%)	751.7 (100%)	762.6 (101.5%)
MOE-2	289.2 (94.0%)	307.6 (100%)	326.4 (106.1%)

Based on Table 5, when the constant rate at which Red forces are attrited by Blue forces (a_0) decreases by 10%, MOE-1 decreases 5.2% and MOE-2 decreases 1.7%. When a_0 increases 10%, MOE-1 increases 5.2% and MOE-2 increases 1.8%. For the constant rate at which Blue forces are attrited by Red forces (b_0), when b_0 increases by

10%, MOE-1 decreases 1.4% and MOE-2 decreases 6.0%, and when b_0 decreases 10%, MOE-1 increases 1.5% and MOE-2 increases 6.1%. If the same amount of effort or cost are required to either increase a_0 by 10% or decrease b_0 by 10% for the Blue force, increasing a_0 is more efficient for improving Red casualties (MOE-1) than decreasing b_0. On the contrary, decreasing b_0 is more efficient for improving Blue survivors (MOE-2) than increasing a_0.

2. ANalysis Of VAriance (ANOVA).

In this section, an analysis tool known as the *analysis of variance*, abbreviated ANOVA, is considered. The use of ANOVA requires some basic assumptions, such as; the observations that are obtained are independent and normally distributed; all the observations have the same variance; and the mean of each observation can be represented as a linear combination of certain unknown parameters. [Ref. 11 : p. 644]. The One-way Layout (One-way ANOVA) will be discussed here.

It is assumed that the output of each Basic model run (a cell of the output matrix produced by the Advanced model in Chapter 2) is an independent battle result, and eight observations (based on 8 Blue options) on each column (based on each Red option) have the same variances. With these assumptions, the actual output of the Advanced model is fitted to the normal distribution. Figure 28 and 29 show how Red casualties (MOE-1) and Blue survivors (MOE-2) fit the normal distribution. In each figure, all four graphs (histogram and normal density function, normal cumulative distribution function, normal probability plot, and normal likelihood surface) verify that these observations are normally distributed. [Note: all 32 observations are within the 95% K-S bound[2] on normal probability plot (the third graph in Figures 28 and 29)]. It is also verified that Red to Blue casualty ratio (MOE-4) fits the normal distribution by using the same methods for MOE-1 and MOE-2.

To apply an AVOVA test, the maximum attrition rate coefficients, a_0 and b_0, are multiplied by 1.1, respectively (i.e., both maximum attrition rate coefficients are increased by 10%). The problem is to compare the mean values of each MOE output for the different Red options between the two battle cases; original outputs of the Advanced model without any changes, and when both a_0 and b_0 are multiplied by 1.1. Each Red option has eight independent MOE outputs based on eight different Blue options. The results for both battle cases are given in Figure 30.

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[2] ***Kolmogorov-Smirnov bound*** [Ref. 11 : p. 552].

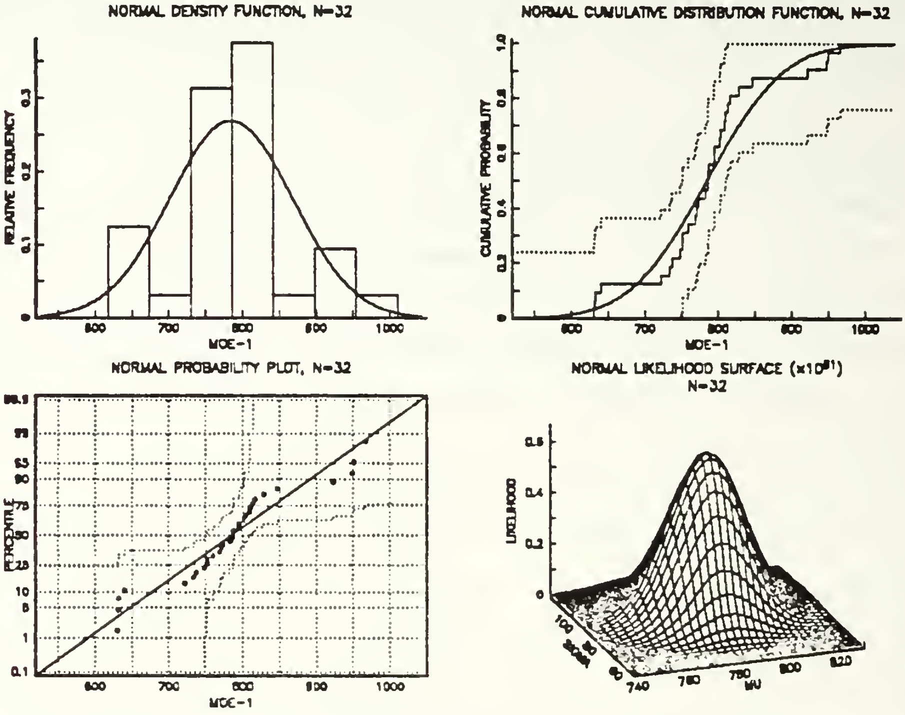

Figure 28. Fitting the Red casualties (MOE-1) of the Advanced model output to Normal Distribution.

In Figure 30, ROW represents the eight different Blue options, columns 1 through 12 (C1-C12) represent the original Advanced model outputs without any modifications, and columns 21 through 32 (C21-C32) represent modified Advanced model outputs with increased maximum attrition rate coefficients. Also, C1 and C21 represent Red option-1, C2 and C22 for Red option-2, C3 and C23 for Red option-3, C4 and C24 for Red option-4, etc. The MINITAB computer software [Ref. 12] was used to compute the ***value of F-Ratio*** for the One-Way AVOVA test. The following example shows the MINITAB output for the One-Way ANOVA test. The example compares the mean difference between C1 and C21.

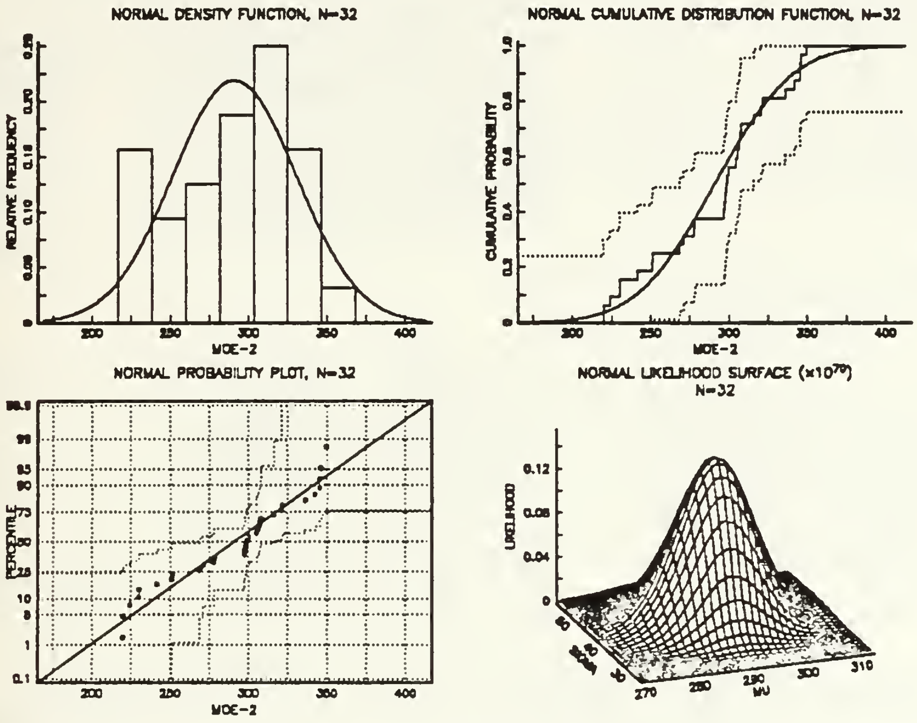

Figure 29. Fitting the Blue survivors (MOE-2) of the Advanced model output to Normal Distribution.

```
A. RED CASUALTIES (MOE-1)

ROW   C1     C2     C3     C4       C21    C22    C23    C24

1   759.6 802.3 949.2 828.5     769.3 832.8 961.9 857.7
2   795.2 751.7 951.3 783.0     807.1 779.3 959.9 810.6
3   786.9 795.4 967.3 817.1     798.2 825.8 977.4 846.3
4   771.0 752.0 923.0 787.0     782.3 779.9 936.0 814.4
5   768.6 747.8 810.1 733.7     791.7 775.7 814.2 756.0
6   813.9 639.9 808.9 630.5     839.8 660.8 814.7 646.4
7   803.5 737.4 847.3 722.1     828.4 765.4 845.6 744.4
8   773.9 632.4 787.7 631.3     798.2 652.5 791.9 646.8


B. BLUE SURVIVORS (MOE-2)

ROW   C5     C6     C7     C8       C25    C26    C27    C28

1   349.9 278.1 219.9 230.1     341.5 263.5 206.9 212.1
2   321.1 307.6 220.0 268.9     311.4 294.8 207.1 253.3
3   321.7 278.4 241.6 230.4     312.1 263.8 228.3 212.4
4   345.5 297.3 224.4 271.0     336.6 283.6 211.2 255.6
5   336.3 298.7 297.5 251.1     324.7 284.0 293.0 234.2
6   316.5 346.3 297.9 305.0     304.8 334.3 293.3 291.5
7   305.7 299.1 307.1 251.4     292.7 284.4 300.7 234.5
8   345.5 342.3 300.4 308.0     335.0 330.2 295.3 294.7


B. RED TO BLUE CASUALTIES (MOE-4)

ROW   C9     C10    C11    C12        C29    C30    C31    C32

1     3.80   2.95   2.88   2.59       3.69   2.91   2.80   2.54
2     3.47   3.10   2.88   2.79       3.38   3.05   2.80   2.73
3     3.45   2.93   3.14   2.56       3.36   2.89   3.04   2.51
4     3.77   2.98   2.83   2.82       3.67   2.93   2.76   2.77
5     3.60   2.98   3.21   2.45       3.51   2.92   3.17   2.39
6     3.49   3.14   3.21   2.57       3.42   3.06   3.17   2.50
7     3.29   2.94   3.49   2.42       3.22   2.88   3.39   2.36
8     3.79   3.05   3.16   2.61       3.71   2.97   3.11   2.53
```

Figure 30. MOE outputs for both battle cases; original battle, and both a_0 and b_0 increased by 10 percent.

< EXAMPLE >

```
ANOVA-ONEWAY on C1 C21

ANALYSIS OF VARIANCE
SOURCE      DF        SS        MS        F
FACTOR       1      1267      1267     2.84
ERROR       14      6256       447
TOTAL       15      7523
                                    INDIVIDUAL 95 PCT CI'S FOR MEAN
                                    BASED ON POOLED STDEV
LEVEL        N      MEAN     STDEV  --+---------+---------+---------+----
C1           8    784.07     18.94   (----------*-----------)
C21          8    801.87     23.13             (-----------*----------)
                                    --+---------+---------+---------+----
POOLED STDEV =     21.14              770       784       798       812
```

The example compares column 1 and column 21 (C1 and C21), which are Red casualties (MOE-1) of Red option-1 for both battle cases. The ***value of F-Ratio*** 2.84, in this example, is compared with the table value for the $F_{1,14}$ (F-Distribution with degrees of freedom 1 and 14). If the significant level, α, is 0.05, the table value for $F_{1,14}$ is 4.60. Consequently, because the ***value of F-Ratio*** is less than the table value for $F_{1,14}$ ($2.84 < 4.60$), the difference for mean of Red casualties (MOE-1) on Red option-1 between above two battle cases is not significant at the 0.05 significance level.

All results for the One-Way ANOVA test between C1-C12 and C21-C32 are given in Table 6. Like the example, no results are significant with a significance level of 0.05. This implies that increasing both a_0 and b_0 by 10% do not make any differences at 0.05 significance level for all possible battle cases in this given scenario.

Table 6. RESULTS OF ONE-WAY ANOVA TEST WHEN THE MAXIMUM ATTRITION RATE COEFFICIENTS ARE CHANGED.

Red options	MOE-1	MOE-2	MOE-4
Red option-1	2.84	1.55	0.92
Red option-2	0.66	1.07	2.40
Red option-3	0.03	0.18	0.39
Red option-4	0.35	1.06	0.70

D. WEISS PARAMETER

In Chapter 2, ***the Weiss parameter*** was discussed by showing how the attacker's (or defender's) casualty rate per time changes by attacker to defender force ratio (see Figures 5 and 6 in Chapter 2). At that time, it was also shown how the attacker's (or defender's) casualty rate per time changes different when w (Weiss parameter) is changed from 0 to 1.0. In this section, two approaches for sensitivity analysis of w will be applied.

First, only w_y (Weiss parameter Blue engaging Red) varies from 1.0 to 0.6, which implies that the type of fire for the Blue force changes to area-fire from aimed-fire. Figure 31 shows that both Red casualties (MOE-1) and Blue survivors (MOE-2) increase as w_y decreases. In other words, fractional casualties per unit time for Red (attacker) increase as w_y decreases, and fractional casualties per unit time for Blue (defender) increase as w_y decreases. This fact can be verified from Figures 5 and 6 in Chapter 2. [NOTE : Red to Blue force size ratio ($A/D =$ Red/Blue) is between 2.92 and 2.66 in Figure 32 while w_y varies from 1.0 to 0.6, and fractional casualties per unit time for each w (when $w = 0$, 1/4, 1/2, and 1.0) consistently varies between 2.92 and 2.66 in Figures 5 and 6 in Chapter 2]. Figure 31 also depicts that the increasing rate of MOE-1 is greater than that of MOE-2. In other words, Red casualties are more sensitive to the parameter, w_y. Figure 32 is compared for Red to Blue casualty ratio and Red to Blue force ratio. Red to Blue casualty ratio increases as w_y varies from 1.0 to 0.6, while Red to Blue force ratio decreases as w_y varies. This is a reasonable tendency in theoretical battle situations.

Second, outcomes are analyzed as if the w_y (Weiss parameter Blue engaging Red) and w_x (Weiss parameter Red engaging Blue) approach the same value. In other words, the type of fire for the Blue force turns to area-fire from aimed-fire, and type of fire for the Red force turns to aimed-fire from area-fire. Figure 33 shows that Red casualties

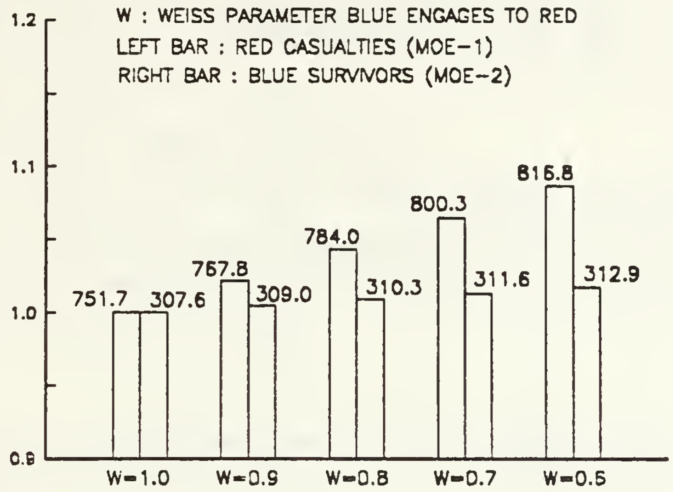

Figure 31. Change of Basic model output (MOE-1 and MOE-2) based on Weiss parameter for Blue engaging Red.

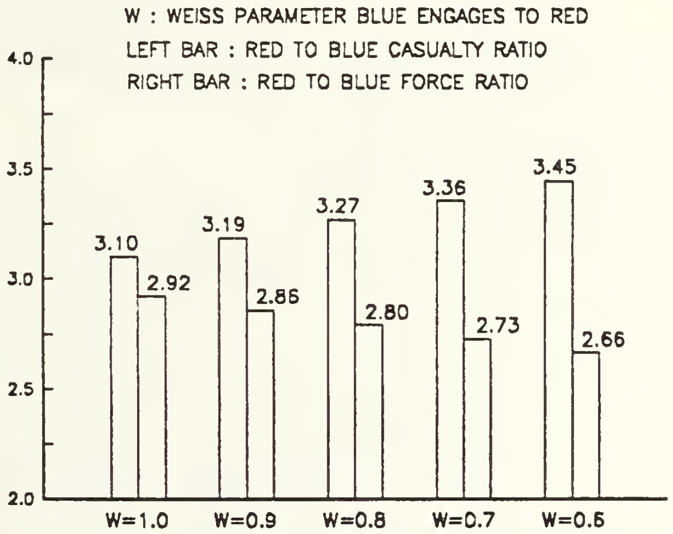

Figure 32. Change of Basic model output (Red to Blue casualty ratio and force ratio) based on Weiss parameter for Blue engaging Red.

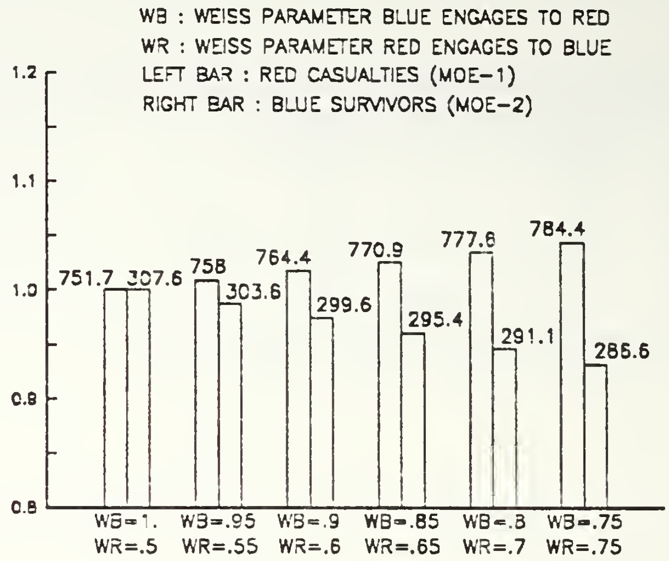

Figure 33. Change of the Basic model output (MOE-1 and MOE-2) when Weiss parameters for both Red and Blue approach the same value.

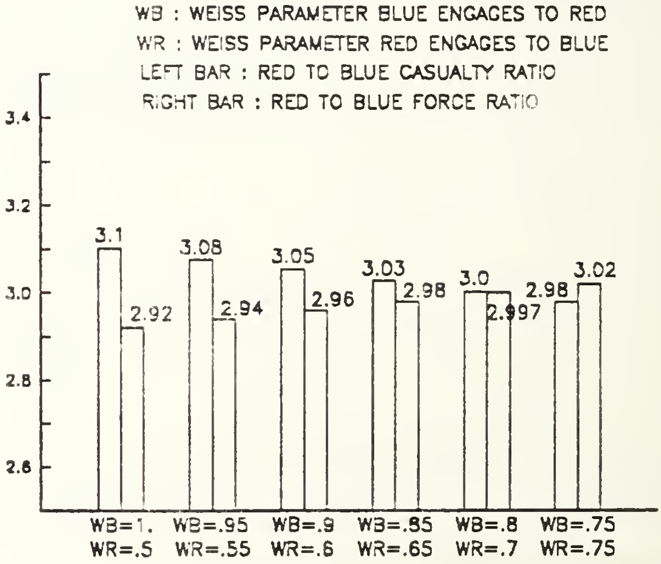

Figure 34. Change of Red/Blue casualty and force ratio in Basic model when Weiss parameters for both Red and Blue approach the same value.

(MOE-1) increase linearly as w_y and w_x get closer in value, while Blue survivors (MOE-2) decrease linearly. Figure 34 depicts the differences between Red to Blue casualty ratio and force ratio. The Red to Blue casualty ratio decreases as w_y and w_x get closer to each other, while Red to Blue force ratio increases. Note that Red to Blue casualty and force ratio are almost equal when w_y is 0.8 and w_x is 0.7, and the Red to Blue force ratio becomes greater than the casualty ratio thereafter.

Finally, the One-Way ANOVA test is also applied in the sensitivity analysis of the first case above. The test compares the original basic model output and the output when Weiss parameter for Blue engaging Red is changed to 0.9 from 1.0. All ***value of F-Ratio*** results for the test are given in Table 7.

Table 7. RESULTS OF ONE-WAY ANOVA TEST WHEN THE WEISS PARAMETER BLUE ENGAGING RED ARE CHANGED.

Red options	MOE-1	MOE-2	MOE-4
Red option-1	*4.79*	0.12	0.31
Red option-2	0.36	0.01	*5.60*
Red option-3	0.68	0.05	0.29
Red option-4	0.69	0.02	3.88

Since the compared values (MOE-1, MOE-2, and MOE-4) and the number of observations are same as those shown in the previous section (see Figure 30). $F_{1,14}$ (F-Distribution with degree of freedom 1 and 14) is utilized. If the significant level, α , is 0.05, the table value for $F_{1,14}$ is 4.60. There exist two values which are larger than 4.60 in Table 7 (4.79 and 5.60), which are MOE-1 in Red option-1 and MOE-4 in Red option-2. This implies that the mean number of Red casualties of eight Blue options (i.e., eight observations) with Red option-1 changes significantly if w_y (Weiss parameter Blue engaging Red) decreases from 1.0 to 0.9. The same result occurs for the mean of Red to Blue casualty ratio of eight Blue options with Red option-2.

To confirm these results, ***Two Sample t-Test***[3] was applied for both cases. The t-Test can be employed because it was assumed and verified that comparing two 8 observations have same variances and each observation (each battle output : MOE values) is a random sample from a normal distribution as explained in the previous section. The above two significant cases are tested as examples. The following examples show the results of the two sample t-test with null hypothesis and alternative hypothesis in case of the two-tail test.

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[3] Page 506, Morris H. DeGroot, *Probability and Statistics (Second Edition)* , by Addison-Wesley Publishing Company, Inc. 1986.

Example (Case 1)

Let $\overline{X}$ be the mean number of Red casualties of eight Blue options with Red option-1 in original Basic model output.

Let $\overline{Y}$ be the mean number of Red casualties of eight Blue options with Red option-1 after changing w_x to 0.9 from 1.0.

Test the following hypothesis with a significant level $\alpha = 0.05$.

$$H_0 : \overline{X} = \overline{Y}$$
$$H_a : \overline{X} \neq \overline{Y}$$

Let S_X^2 and S_Y^2 be the sums of squares as follows:

$$S_X^2 = \sum_{i=0}^{m} (X_i - \overline{X}_m)^2 \qquad S_Y^2 = \sum_{i=0}^{n} (Y_i - \overline{Y}_n)^2 \tag{4.1}$$

Also let the statistic U be defined by the following relation:

$$U = \frac{(m+n-2)^{1/2}(\overline{X}_m - \overline{Y}_n)}{(\frac{1}{m} + \frac{1}{n})^{1/2}(S_X^2 + S_Y^2)^{1/2}} \tag{4.2}$$

Since the alternative hypothesis is two-sided, the test procedure would reject H_0 if either $U < c_1$ or $U > c_2$, where the constants c_1 and c_2 are chosen so that when H_0 is true,

$$\Pr(U < c_1) + \Pr(U > c_2) = \alpha.$$

In this example, the sample sizes are m=8 and n=8, and the value of the statistic U defined by equation (4.2) is 2.18. Also, by use of a table of the t distribution with 14 degrees of freedom (m+n-2), c_1 and c_2 are -2.145 and 2.145, respectively. Since the value of the statistic U is greater than 2.145 ($U > c_2$), the null hypothesis is rejected for the given specified level of significance, $\alpha = 0.05$.

Example (Case 2)

Let $\overline{X}$ be the mean Red to Blue casualty ratio of eight Blue options with Red option-2 in original Basic model output.

Let $\overline{Y}$ be the mean Red to Blue casualty ratio of eight Blue options with Red option-2 after changing w_x to 0.9 from 1.0.

In this example, the sample sizes are $m=8$ and $n=8$, and the value of the statistic U defined by equation (4.2) is 2.37. Also, as in the previous example, since the value of the statistic U is greater than 2.145 ($U > c_2$), the null hypothesis is rejected for the given specified level of significance, $\alpha = 0.05$.

These examples verify the results from the One-Way ANOVA test which is shown in Table 8. Recall, from Table 8, there were only two significant cases (4.79 and 5.60) which were greater than 4.60 (table value for F-distribution with degree of freedom 1 and 14).

E. COUNTERMEASURES

The practicing weapon systems analyst must be well aquainted with the more general principles of countermeasures, for his task is often that of evaluating the potential of proposed countermeasures. Also, countermeasures are often likely to improve survivability, especially for defenders. Indeed, the battle is often based on "see-sawing" advantages. While it is usually impossible to anticipate enemy reactions to an initiative, there is a rather satisfactory or useful mode of approach to this problem. The tank was the countermeasure to the machinegun, while antitank mines and shaped charge warheads are countermeasures to the tank threat.

In this model, two Blue courses of action are considered against two Red courses of action. It is assumed that the Blue force can increase indirect fire by expanding the firing time of the Blue artillery weapons and can also increase mine density in a given minefield, while the Red force may use a mine-plow to break through a Blue minefield and may also use smoke for restricting the firepower of the Blue force's direct fire. It is also assumed that Red smoke does not affect its own direct fire.

The quantitative amounts of effects for the different parameters, depending on which course of action is employed, are defined as follows:

- If the Red forces use mine-plows : decrease by 70% the attrition rate coefficient for minefields.
- If the Red forces use smoke : decrease by 10% the attrition rate coefficient to Red force from Blue force.
- If the Blue forces increase indirect fire : expand firing time of Blue artillery to 20 minutes from 10 minutes.
- If the Blue forces increase mine density : increase the number of mines in a given minefield by 100%.

Table 8 provides payoff matrices for Red and Blue courses of action, which shows both Red casualties and Blue survivors (MOE-1 and MOE-2). Based on Table 8, if the Blue force can use only one of two courses of action, increasing its indirect fire is better than increasing mine density (MOE-1 : 722.8 > 705.1, MOE-2 : 305.9 > 303.1) when the Red forces use the mine-plows. Recall that the larger MOE values are better for the Blue force. However, when the Red forces use smoke, increasing mine density is better for Blue than increasing indirect fire for the Blue force (MOE-1 : 822.6 > 774.4, MOE-2 : 316.4 > 313.1). From the above facts, the Blue commander can perceive that the number of mines in a minefield do not have much effect on Red's mine-plows, so that Blue may need another course of action to attrite Red mine-plows. Table 8 also shows that if Red and Blue forces employ all their available courses of action, the Red force will have larger advantages than the Blue force (see Table 8, MOE-1 : 718.8 < 751.7, MOE-2 : 305.0 < 307.6).

Figures 35 and 36 depict how Red casualties (MOE-1) and Blue survivors (MOE-2) change based on each course of action. For example, in Figure 35, there is a small difference in Red casualties for Blue courses of action 2 and 3 (B2 and B3) if the Red force selects its course of action 3 or 4 (R3 or R4). These two figures also show a quantitative difference of MOE values for each course of action, so the reader can easily tell the differences by the height of each pillar.

Figures 37 and 38 show how Red to Blue casualty ratio and force ratio change based on Red and Blue's respective course of action. From these figures, the reader can see the trend of the change of Red to Blue casualty ratio and force ratio for each Red and Blue courses of action. Figure 38 has almost the reverse shape of that of Figure 37, which implies that the Red to Blue casualty ratio and the Red to Blue force ratio have negative correlation.

Table 8. PAYOFF MATRIX FOR RED AND BLUE COURSE OF ACTIONS (MOE-1/MOE-2).

Courses of action				RED Force			
				use Mine-plow		do not use Mine-plow	
				use Smoke		use Smoke	
				YES	NO	YES	NO
BLUE Force	increase Indirect fire	increase Mine density	YES	718.8/305.0	758.1/310.3	888.3/330.0	927.5/336.6
			NO	683.5/300.7	722.8/305.9	774.4/313.1	813.7/318.8
	do not increase Indirect fire	increase Mine density	YES	655.9/298.3	705.1/303.1	822.6/316.4	862.0/322.2
			NO	631.6/296.3	670.2/300.4	712.4/302.4	751.7/307.6

In Figures 35 and 36, the following abbreviations apply:

R1 = Red force uses both Mine-plow and Smoke.
R2 = Red force uses only Mine-plow.
R3 = Red force uses only Smoke.
R4 = Red force does NOT use either Mine-plow or Smoke.

B1 = Blue force increases both Indirect-fire and Mine density.
B2 = Blue force increases only Indirect-fire.
B3 = Blue force increases only Mine density.
B4 = Blue force does NOT increase either Indirect-fire or Mine density.

In Figures 37 and 38, the following abbreviations apply:

1 on Red courses of action = R1 in Figures 35 and 36
2 on Red courses of action = R2 in Figures 35 and 36
3 on Red courses of action = R3 in Figures 35 and 36
4 on Red courses of action = R4 in Figures 35 and 36

1 on Blue courses of action = B1 in Figures 35 and 36
2 on Blue courses of action = B2 in Figures 35 and 36
3 on Blue courses of action = B3 in Figures 35 and 36
4 on Blue courses of action = B4 in Figures 35 and 36

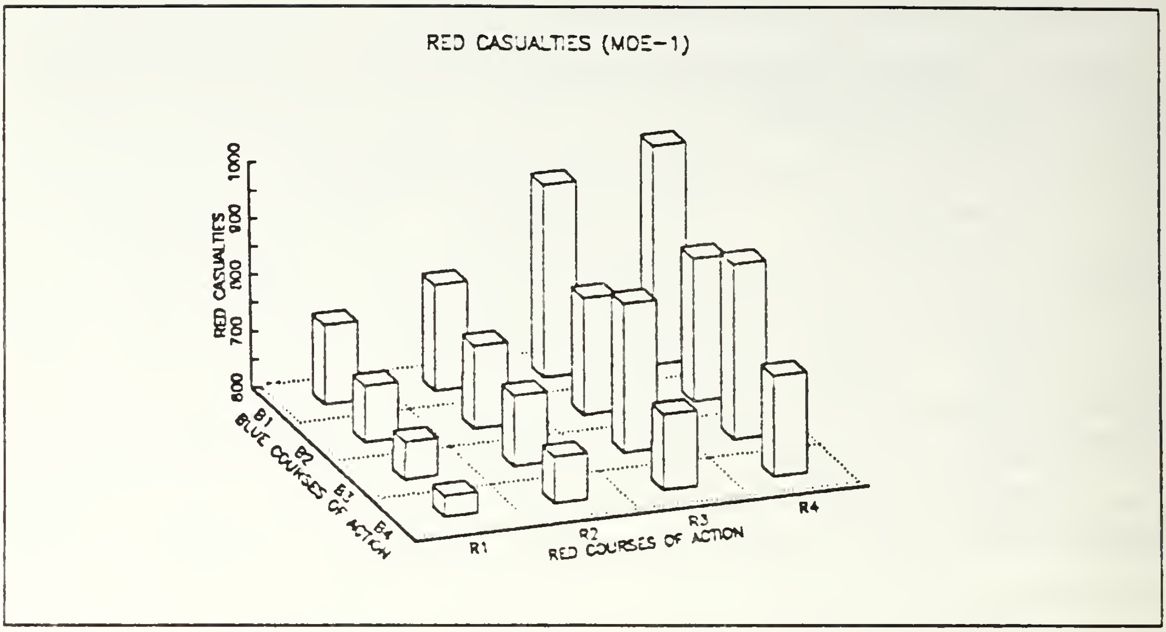

Figure 35. 3-Dimensional view of payoff matrix for Red casualties.

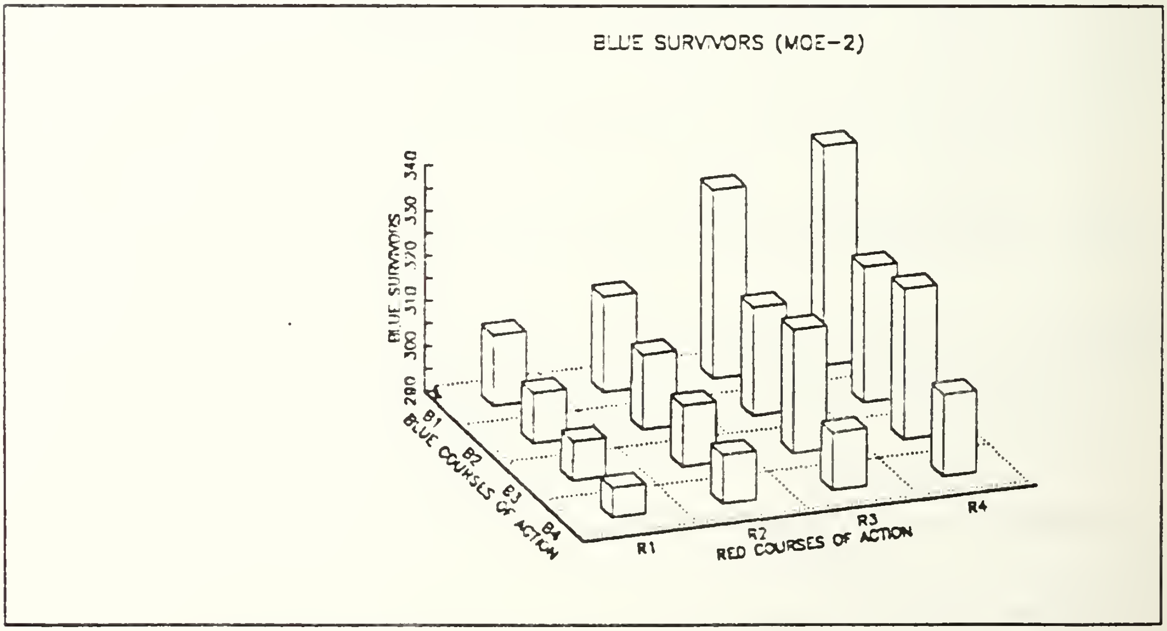

Figure 36. 3-Dimensional view of payoff matrix for Blue survivors.

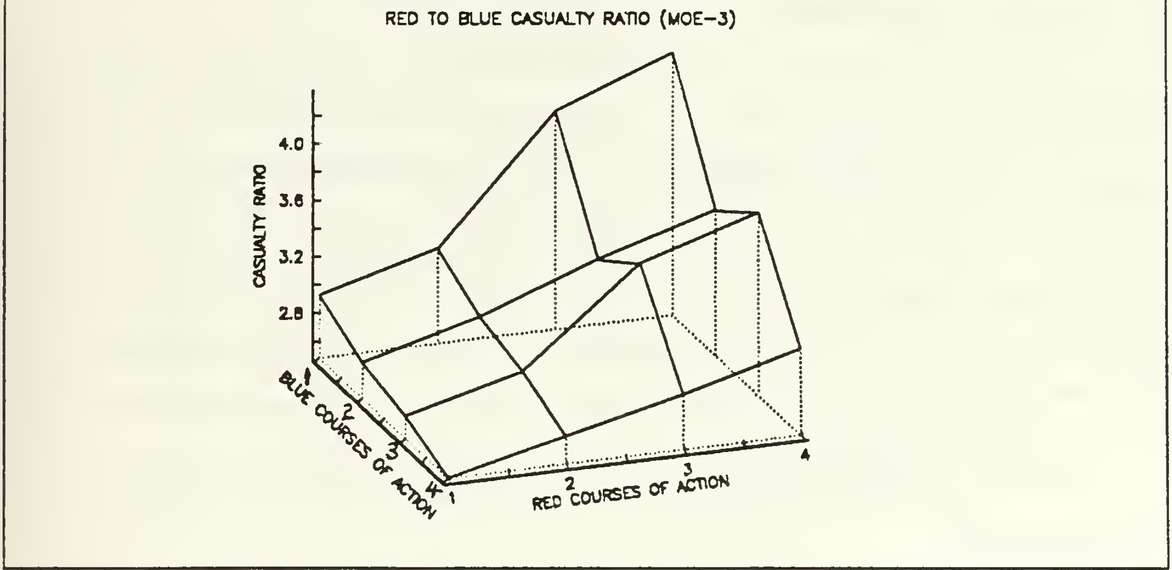

Figure 37. 3-Dimensional view of payoff matrix for the Red to Blue casualty ratio.

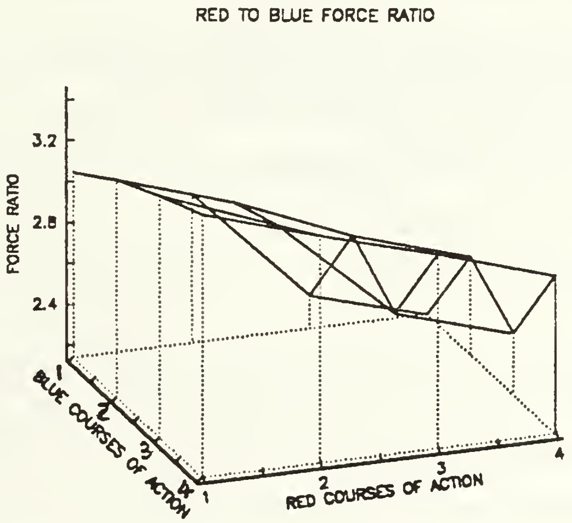

Figure 38. 3-Dimensional view of payoff matrix for the Red to Blue force ratio.

F. MODEL ENRICHMENT

The important question answered in this chapter is "Is this deterministic model performing in a reasonable fashion?" To support this question, this section will provide answers to the following questions, "Can a Red and Blue force size ratio affect the attacking force's speed?" (i.e., Is it better for the Red force to move fast when the Red to Blue force ratio is large versus when the Red to Blue force ratio is small?). If the answer is "yes" for this question then "How are they related ?" and "How does it affect the duration of battle (MOE-4) ?" These questions arise because the duration of battle in the Basic model did not vary by changing any of the parameters during the sensitivity analyses in previous sections.

In order to solve these problems, equation (2.16) in Chapter 2 was modified as given by equation (4.3).

$$S_{new} = S_{old} \times (1 - \frac{a_c}{a_0})^v + S_{\min} \qquad where \quad S_{\min} = 0.3 \times (\frac{RF_c}{BF_c}) \tag{4.3}$$

where

v : power factor, based on different weapon types

S_{new} : updated speed of attacking force

S_{old} : speed of attacking force for previous time step

$S_{\min}$: minimum speed for the attacking force

a_c : current attrition coefficient

a_0 : maximum attrition coefficient

RF_c : current Red force size

BF_c : current Blue force size

In equation (4.3), it is assumed that Red to Blue force ratio affects the minimum speed of Red (attacker) force. In other words, the Red force's minimum speed is proportional to the Red to Blue force ratio ($S_{\min} \propto RF_c/BF_c$). It is also assumed the Red to Blue force ratio is greater than one. The 0.3 is a constant value under the assumption that the Red force can maneuver at least 0.3km per hour regardless of the Red to Blue force ratio value. The linear function for the minimum speed is shown in left portion of Figure 39. The function shown in right portion of Figure 39 represents the case when the attacker's minimum speed is not a linear function of Red Blue force ratio. In this chapter, the

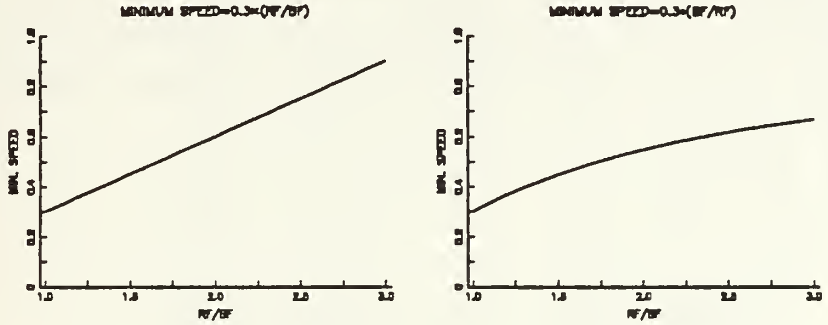

Figure 39. Two different functions for minimum speed.

linear function case, given in left portion of Figure 39, is applied to the basic model and analyzed in Figures 40 and 41.

Figure 40 shows differences of the Red to Blue casualty ratio (MOE-3) between the Basic model (which has constant minimum speed) and the Enriched model (which regards the attacker's minimum speed as a linear function of Red Blue force ratio) when each parameter is altered as follows:

NO CHANGE : no parameters are changed
↑ *MD* : Blue increases the Mine density.
↑ *IF* : Blue increases the Indirect fire.
USE MP : Red uses Mine-plow.
USE SM : Red uses Smoke.

Figure 40 illustrates that as the mine density and indirect fire increase for both models so do Red Blue casualty ratios. When mine-plow and smoke are employed for both models, Red Blue casualty ratios decrease. These results are reasonable from a military standpoint. Even though there exist somewhat differences in increasing or decreasing

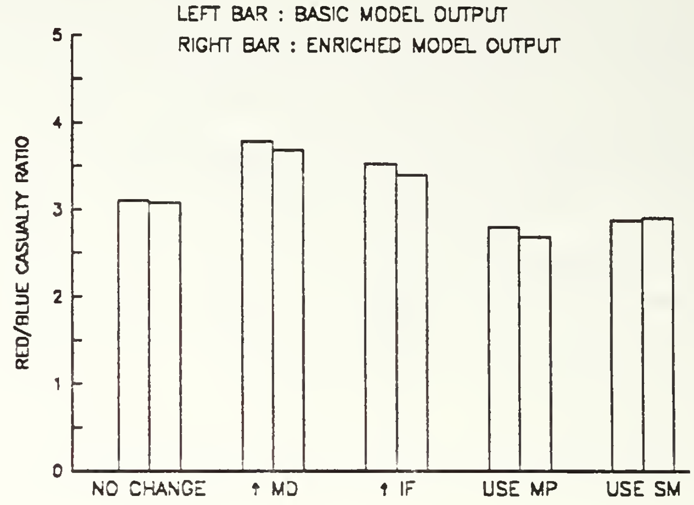

Figure 40. Comparison of RED/BLUE casualty ratio (MOE-3) between Basic and Enriched model.

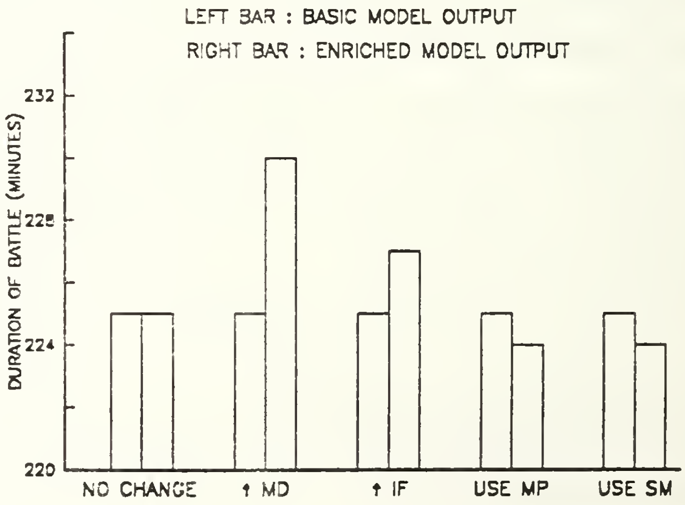

Figure 41. Comparison of duration of battle (MOE-4) between Basic and Enriched model.

Red Blue casualty ratio between Basic and Advanced model, both models change with a similar tendency based on alteration of each parameter.

Figure 41 shows differences of duration of battle (MOE-4) between the Basic model and the Enriched model. As expected, battle time is longer when Blue increases its mine density or indirect fire, and battle time is shorter when Red uses its mine-plow or smoke. Based on the above analysis with both Figures 40 and 41, the Enriched model appears to produce more reasonable results than the Basic model.

V. SUMMARY AND FUTURE DIRECTIONS

A. SUMMARY

This thesis has developed a deterministic air-land combat model using network attribute terrain data. Even though the model utilized terrain data for battalions and regiments, it may accept terrain data for larged sized forces. The model was run under a given scenario of specific battle conditions using an assigned battle area in the Republic of Korea. Three avenues of approach were employed in the model for the attacking force to reach the defending force. Based on the disposition of the forces (personnel, minefields, indirect fire, and so forth), the model outputs (MOEs) provide the military planner with information on preparing better defensive plans.

The primary focus of the thesis was to demonstrate various methods for analyzing model outputs. In this respect, the model provided sufficient data for analysis, which was performed in Chapters 3 and 4. In Chapter 4, sensitivity analysis varying specific parameters produced reasonable results, and also determined those parameters which were most volatile to change. The important results from sensitivity analyses are as follows:

1. If Blue has proper conditions (discussed in Chapter 4) on ambush points, reinforcing an additional platoon at the ambush point is better than at the main force areas.
2. As both maximum attrition rate coefficients (a_0 and b_0) increase, firepower effectiveness (or loss rate exchange) of Blue force is gradually reduced.
3. Both Red casualties and Blue survivors increase as w_y (Weiss parameter for Blue engaging Red) decrease, but Red casualties are more sensitive to w_y than Blue survivors.
4. When Weiss parameters for both Red and Blue approach the same value, both Red and Blue casualties decrease and the Red/Blue casualty ratio also decreases, which implies that firepower effectiveness of Red force increases.
5. The number of mines in Blue minefields do not have much effect on Red's mineplows.
6. If Red uses smoke, increasing the number of mines in Blue minefields is better than increasing Blue indirect fire.

In addition to the above results, the model pointed out that Blue needs to consider new courses of action for attrition to Red on Avenue-22 in the BATTLE1 case which was discussed in section C of Chapter 3. The model was enriched by using a modified equation for computing the attacking units' speed.

B. FUTURE DIRECTIONS

The deterministic model developed in this thesis is neither a complete nor perfect model. The author focused his efforts on analyzing the model outputs with various methodologies. Additional research is needed for improving the model. Other analytical methodologies, not covered in this thesis, should be explored. A limitation of this deterministic model is how to specify and determine more realistic attrition rate coefficient for each weapon system, to be used in Lanchester's Linear and Square law. However, simulation methods may be a possible approach to find more accurate attrition rate coefficients for weapon systems.

There are numerous factors which affect a battalion or regimental size battle. Therefore, the model developed in this thesis can be expanded by adding more combat types such as Close Air Support (CAS) and other newly developed weapon systems. The inclusion of these factors makes the model more complicated, yet allows for more realistic outputs. As for one way of dealing with new weapon systems, different value of μ (power factor based on different weapon types in Figure 7 of Chapter 2) could be used.

If the battle area has many terrain features (such as small hills, streams, bridges, reseviors, and so forth) in small battle areas, some attrition rate coefficients may need to be changed. In order to deal with these factors, different analytical approaches are required. Simulations may help to obtain data outputs for comparison to real world data. Verification and evaluation with historical data is necessary before this model is used to test actual combat plans or scenarios.

It is recommanded that the deterministic nature of the model be retained, as opposed to applying stochastic processes, because the purpose of this model is to generate battle outcomes traceable to specific input parameters. In other words, it is not suggested that stochastic variables be treated by a Monte Carlo process. Rather, the parameters are varied for different runs to maintain audit trail control for the purposes of analysis.

Finally, because only dismounted units (infantry forces) were considered in this model as an initial run, mounted units (vehicles such as tanks, APCs, and trucks) also should be considered for future runs. This requires some modifications to the model to incorporate different parameters based on vehicle types.

APPENDIX A. MODELS INPUT DATA

This is a formation of the input data for both models (Basic and Advanced) for dismounted (Infantry) unit cases.

Arc No.	Nodes (tail-head)		Passing time(min)	Distance	Width	Speed
1	1	2	31.5	2.1	0.006	4.
2	1	6	67.5	4.5	0.356	4.
3	2	3	16.5	1.1	0.506	4.
4	2	4	15.33	1.15	0.358	4.5
5	3	9	41.25	2.75	0.011	4.
6	4	5	32.57	1.9	0.254	3.5
7	4	11	28.67	2.15	0.558	4.5
8	5	7	40.29	2.35	0.004	3.5
9	5	11	60.0	3.	0.112	3.
10	6	7	21.43	1.25	0.554	3.5
11	6	8	31.5	2.1	0.106	4.
12	7	12	19.71	1.15	0.004	3.5
13	8	13	33.75	2.25	0.006	4.
14	9	10	25.0	1.25	0.002	3.
15	9	19	54.0	3.6	0.026	4.
16	10	11	65.0	3.25	0.002	3.
17	10	15	75.0	3.75	0.002	3.
18	10	20	107.0	5.35	0.002	3.
19	11	14	18.67	1.4	0.098	4.5
20	11	15	34.29	2.0	0.054	3.5
21	12	13	19.71	1.15	0.154	3.5
22	12	14	27.43	1.6	0.049	3.5
23	13	25	52.5	3.5	0.406	4.
24	14	16	11.25	0.75	0.066	4.
25	14	17	19.33	1.45	0.258	4.5
26	15	16	26.0	1.3	0.152	3.
27	15	18	15.43	0.9	0.204	3.5
28	16	17	17.14	1.0	0.084	3.5
29	16	18	14.25	0.95	0.076	4.
30	17	23	8.67	0.65	0.328	4.5
31	17	24	12.86	0.75	0.354	3.5
32	18	21	10.5	0.7	0.256	4.
33	19	20	51.43	3.0	0.049	3.5
34	20	21	21.75	1.45	0.176	4.
35	20	28	13.5	0.9	0.506	4.
36	21	22	18.86	1.1	0.224	3.5
37	22	23	9.43	0.55	0.704	3.5
38	22	27	12.0	0.7	0.454	3.5
39	23	27	8.67	0.65	0.678	4.5
40	24	25	8.57	0.5	0.574	3.5
41	24	26	12.86	0.75	0.274	3.5
42	25	26	8.0	0.6	0.328	4.5
43	26	27	8.0	0.6	0.408	4.5
44	27	28	33.75	2.25	0.066	4.

APPENDIX B. BASIC MODEL

This is a computer program using Fortran-77 for the basic model.

```
C
C ---< BASIC MODEL >---  MADE BY   LEE, JAE YEONG (1988.2.6) ---
C
      INTEGER    NA, NN, NOA, NOP, RBN, RRESER, BCO, PLTN
      PARAMETER (NA=44, NN=28, NOA=3, NOP=2, PLTN=40)
      PARAMETER (RBN=500, RRESER=150, BCO=170)
      INTEGER    REDAVE(NOA),SMAVE(NOA),PMAVE(NOA)
      INTEGER    ARC(NA),TAIL(NA),HEAD(NA),TAVE(NOA)
      INTEGER    PMARC(5),SMARC(3),IDARC(4,0:1001)
      INTEGER    IFA(4,1000),MFA(4,1000),DFA(4,1000)
      INTEGER    POIF,BLUEP1,BLUEP2,ANS1,ANS2,ANS3,ANS4
      INTEGER    INPUT,OUTPUT,TP1,TP2,DIF,DPMF,DSMF,INCRE,WID
      INTEGER    IFANS,MFANS,DFANS,TEND
      REAL     DIST(NA),WIDTH(NA),TIME(NA)
      REAL     SPEED(NA),OSPEED(NA),ADSP(NA)
      REAL     BREAKP(4),BREAKT(4)
      REAL     RF(4,0:1001),BF(4,0:1001),WHERE(4,0:1001),SP(4,0:1001)
      REAL     IFC(4,0:1001),MFC(4,0:1001),RDFC(4,0:1001),
     1         IMDC(4,0:1001),BDFC(4,0:1001)
      REAL     RBP(4),IFSUM(4),MFSUM(4),RDFSUM(4),BDFSUM(4)
      REAL     IFCAS,MFCAS,DFCAS,BLEFT1,BLEFT2,WHOLD
      REAL     CLOCK,RANGE,BRDIST,AR,RB

      DATA   DIF,DPMF,DSMF  /10,20,15/
      DATA   PMAVE          /1,3,1/
      DATA   PMARC          /15,19,23,25,32/
      DATA   RANGE          /1.1/
      DATA   RB             /0.0/

      DATA   REDAVE         /0,2,1/
      DATA   POIF           /2/
      DATA   SMAVE          /0,2,1/
      DATA   BLUEP1,BLUEP2  /1,2/

      INPUT = 12
      OUTPUT = 13
C---OPEN OUTPUT FILES !
C---FILE 'TSTEP' HAS RED AND BLUE FORCE SIZES ON EACH AVENUE
C---FILE 'REDCAS' HAS RED CASUALTIES ON EACH AVENUE
      OPEN ( UNIT = OUTPUT, FILE = 'TSTEP' )
      OPEN ( UNIT = 21,     FILE = 'REDCAS' )

         WRITE(6,9)
      DO 10 I = 1, NA
         READ(INPUT,11) ARC(I),TAIL(I),HEAD(I),TIME(I),DIST(I),WIDTH(I),
     1                  SPEED(I)
         WRITE(6,11) ARC(I),TAIL(I),HEAD(I),TIME(I),DIST(I),WIDTH(I),
     1                  SPEED(I)
10    CONTINUE
9     FORMAT(1X,50('-'),/2X,'ARC  TAIL-HEAD  TIME       DIST    WIDTH ',
     1      '  SPEED',/1X,50('-'))
11    FORMAT(3X,I2,2(3X,I2),2X,F6.2,6X,F4.2,4X,F5.3,3X,F5.3)

         CALL  OPTION (NA,NOA,REDAVE,POIF,SMAVE,BLUEP1,BLUEP2,SPEED,
     1                DIST,TIME,PMARC,SMARC,ANS1,ANS2,ANS3)
      IF(ANS1 .EQ. 0) GO TO 999
      IF(ANS2 .EQ. 0) GO TO 999
      IF(ANS3 .EQ. 0) GO TO 999

         DO 19 I = 1,NA
            CALL ASPEED (I,NA,ANS1,SPEED,ADSP)
            SPEED(I) = ADSP(I)
19          OSPEED(I) = SPEED(I)

      WRITE(13,25)REDAVE(1),REDAVE(2),REDAVE(3),SMAVE(1),SMAVE(2),
     1            SMAVE(3),SMARC(1),SMARC(2),SMARC(3),BLUEP1,BLUEP2
      WRITE(6,25) REDAVE(1),REDAVE(2),REDAVE(3),SMAVE(1),SMAVE(2),
     1            SMAVE(3),SMARC(1),SMARC(2),SMARC(3),BLUEP1,BLUEP2
25    FORMAT(//1X,'RED OPTION ===> ',3I3,/1X,'BLUE OPTION',
     1/4X,'* SCATERABLE MINEFIELD ===>',3I3,
     1/4X,'      (LOCATED ARCS)   ===>',3I3,
     1/4X,'* FORCE ALLOCATION =======>',2I3,//)

      NNN = 0
      IUSED = 0
      NEQ12 = 0
      NEQ34 = 0
      DO 5 I = 1,4
         IFSUM(I) = 0.0
         MFSUM(I) = 0.0
         RDFSUM(I) = 0.0
         BDFSUM(I) = 0.0
5     CONTINUE

C---DEFINE INITIAL FORCE LEVEL AND LOCATION !
      RF(1,0) = REDAVE(1)*RBN
      RF(2,0) = (REDAVE(2)*RBN)/2
      RF(3,0) = (REDAVE(2)*RBN)/2
      RF(4,0) = REDAVE(3)*RBN
      DO 28 I = 1,4
         WHERE(I,0) = 0.
         IFC(I,0) = 0.
         MFC(I,0) = 0.
         RDFC(I,0) = 0.
         IMDC(I,0) = 0.
         BDFC(I,0) = 0.
28       RBP(I) = RB*RF(I,0)
      BF(1,0) = BLUEP1*BCO + PLTN/2
      BF(2,0) = BLUEP1*BCO + PLTN/2
      BF(3,0) = BLUEP2*BCO + PLTN/2
      BF(4,0) = BLUEP2*BCO + PLTN/2

      NOC = 0
      INCRE = 1
      DO 9999 IT = 1,500,INCRE

      CLOCK = IT
      DO 30 IA = 1,4

         BREAKP(IA) = 0.
         BREAKT(IA) = 0.
            IFC(IA,IT) = IFC(IA,IT-1)
            MFC(IA,IT) = MFC(IA,IT-1)
            RDFC(IA,IT) = RDFC(IA,IT-1)
            IMDC(IA,IT) = IMDC(IA,IT-1)
            BDFC(IA,IT) = BDFC(IA,IT-1)
         RF(IA,IT) = RF(IA,IT-1)
         BF(IA,IT) = BF(IA,IT-1)
         WHOLD = WHERE(IA,IT-1)
         CALL  DETECT (IA,IT,INCRE,WHOLD,WID)
            IF(WID .EQ. 0)  GO TO 999
         IDARC(IA,IT) = WID
         BRDIST = 9999.
         SP(IA,IT) = SPEED(WID)
         TS = (SPEED(WID)/60)*INCRE
         WHERE(IA,IT) = WHOLD + TS

C---IS THERE INDIRECT FIRE ? OR MINEFIELD ? OR DIRECT FIRE ?
            CALL  IDFIND (IA,CLOCK,POIF,IFANS)
            CALL  MFFIND (PMARC,SMARC,WID,MFANS)
            CALL  DRFIND (IA,WHOLD,RANGE,BRDIST,DFANS)

         IFA(IA,IT) = IFANS
         MFA(IA,IT) = MFANS
         DFA(IA,IT) = DFANS

         IF(IFANS.EQ.0 .AND.  MFANS.EQ.0 .AND.  DFANS.EQ.0)  GO TO 30

C---COMPUTE THE CASUALTY OF INDIRECT-FIRE !
         IF(IFANS .EQ. 1) THEN
            CALL  IDFIRE (IA,IT,RF,REDAVE,POIF,IFCAS)
            RF(IA,IT) = RF(IA,IT) - IFCAS
            IFSUM(IA) = IFCAS + IFSUM(IA)
            IFC(IA,IT) = IFC(IA,IT) + IFCAS
         END IF

C---COMPUTE THE CASUALTY BY MINE-FIELD !
         IF(MFANS.EQ.1  .OR.  MFANS.EQ.2) THEN
            CALL  MFIELD (IA,IT,MFANS,INCRE,NA,WID,TIME,RF,MFCAS)
            RF(IA,IT) = RF(IA,IT) - MFCAS
            MFSUM(IA) = MFCAS + MFSUM(IA)
            MFC(IA,IT) = MFC(IA,IT) + MFCAS
         END IF

C---COMPUTE THE CASUALTY BY DIRECT-FIRE !
         IF(DFANS .EQ. 1  .OR.  DFANS .EQ. 2) THEN
            IF( RF(IA,IT) .LT. BF(IA,IT)    .AND.
     1          IUSED .EQ. 0                .AND.
     1          RF(IA,0) .GT. 0.0        )  THEN
```

```
                   RF(IA,IT) = RF(IA,IT) + RRESER
                   IUSED = 1
            END IF
            CALL  DRFIRE (DFANS,DFA,BRDIST,IA,IT,RF,BF,AR,RDFCAS,BDFCAS,
     1                    PLTN,RANGE,NNN,ACO,AMO)

            RF(IA,IT) = RF(IA,IT) - RDFCAS
            BF(IA,IT) = BF(IA,IT) - BDFCAS
            RDFSUM(IA) = RDFCAS + RDFSUM(IA)
            BDFSUM(IA) = BDFCAS + BDFSUM(IA)
            RDFC(IA,IT) = RDFC(IA,IT) + RDFCAS
            BDFC(IA,IT) = BDFC(IA,IT) + BDFCAS
         END IF

         IF(RF(IA,0) .GT. 0.  .AND.  RF(IA,IT) .LE. RBP(IA)) THEN
            CALL  BREAK (IA,IT,NOC,WHOLD,RF,BF,RRESER,BREAKP,BREAKT)
         END IF

C---COMPUTE THE REDUCED SPEED DUE TO THE INDIRECT FIRE OR MINEFIELD OR
C   UNDER THE DIRECT FIRE BASED ON THE RANGE OF TWO FORCES !

            CALL  RSPEED (IA,IT,NA,SPEED,TIME,DIST,WID,RANGE,AR,RF,
     1                    IFANS,MFANS,DFANS,OSPEED,ACO,AMO)

         SP(IA,IT) = SPEED(WID)
         TS = (SPEED(WID)/60)*INCRE
         WHERE(IA,IT) = WHOLD + TS
         IMDC(IA,IT) = IFC(IA,IT) + MFC(IA,IT) + RDFC(IA,IT)

30    CONTINUE

      IF(NEQ12 .NE. 0)  GO TO 36
         BF(1,IT) = MIN( BF(1,IT),BF(2,IT) )
         BF(2,IT) = MIN( BF(1,IT),BF(2,IT) )
36    IF(NEQ34 .NE. 0)  GO TO 37
         BF(3,IT) = MIN( BF(3,IT),BF(4,IT) )
         BF(4,IT) = MIN( BF(3,IT),BF(4,IT) )
37    IF(NEQ12 .NE. 0)  GO TO 38
      IF(DFA(1,IT) .EQ. 2  .AND.  DFA(2,IT) .EQ. 2  .AND.
     1   RF(1,IT) .GT. 0.  .AND.  RF(2,IT) .GT. 0.)  THEN
            BF(1,IT) = (RF(1,IT) / (RF(1,IT)+RF(2,IT))) * BF(1,IT)
            BF(2,IT) = (RF(2,IT) / (RF(1,IT)+RF(2,IT))) * BF(2,IT)
            NEQ12 = IT
      END IF
38    IF(NEQ34 .NE. 0)  GO TO 39
      IF(DFA(3,IT) .EQ. 2  .AND.  DFA(4,IT) .EQ. 2  .AND.
     1   RF(3,IT) .GT. 0.  .AND.  RF(4,IT) .GT. 0.)  THEN
            BF(3,IT) = (RF(3,IT) / (RF(3,IT)+RF(4,IT))) * BF(3,IT)
            BF(4,IT) = (RF(4,IT) / (RF(3,IT)+RF(4,IT))) * BF(4,IT)
            NEQ34 = IT
      END IF
39    WRITE(OUTPUT,40) IT,RF(1,IT),RF(2,IT),RF(3,IT),RF(4,IT)
      WRITE(OUTPUT,40) IT,BF(1,0)-(BDFC(1,IT)+BDFC(2,IT)),
     1                    BF(2,0)-(BDFC(1,IT)+BDFC(2,IT)),
     1                    BF(3,0)-(BDFC(3,IT)+BDFC(4,IT)),
     1                    BF(4,0)-(BDFC(3,IT)+BDFC(4,IT))
```

```
      WRITE(OUTPUT,42)IT,WHERE(1,IT),WHERE(2,IT),WHERE(3,IT),WHERE(4,IT)
      WRITE(OUTPUT,42) IT,SP(1,IT),SP(2,IT),SP(3,IT),SP(4,IT)

      WRITE(21,40) IT,IFC(1,IT),IFC(2,IT),IFC(3,IT),IFC(4,IT)
      WRITE(21,40) IT,MFC(1,IT),MFC(2,IT),MFC(3,IT),MFC(4,IT)
      WRITE(21,40) IT,RDFC(1,IT),RDFC(2,IT),RDFC(3,IT),RDFC(4,IT)
      WRITE(21,40) IT,IMDC(1,IT),IMDC(2,IT),IMDC(3,IT),IMDC(4,IT)
      WRITE(21,40) IT,BDFC(1,IT),BDFC(2,IT),BDFC(3,IT),BDFC(4,IT)
40    FORMAT( 1X,I6,4(3X,F6.1))
41    FORMAT( 1X,I6,4(3X,I6))
42    FORMAT( 1X,I6,4(3X,F6.3))

9999  CONTINUE

999      CALL  PRINT (RBN,BCO,BLUEP1,BLUEP2,RRESER,PLTN,NA,OUTPUT,
     1                IFSUM,MFSUM,RDFSUM,BDFSUM)

C
C-----PRINT FOR CHECKING THE INPUT DATA
C
      WRITE(6,9)
      DO 998 I = 1, NA
998      WRITE(6,11) ARC(I),TAIL(I),HEAD(I),TIME(I),DIST(I),WIDTH(I),
     1               SPEED(I)
      WRITE(6,'(//)')
      STOP   'THIS MODEL IS COMPLETE !   THANK YOU !'
      END

*****************************************************************
*  1. SUBROUTINE FOR SELECTING THE RED AND BLUE OPTIONS
*****************************************************************
      SUBROUTINE OPTION (NA,NOA,REDAVE,POIF,SMAVE,BLUEP1,BLUEP2,SPEED,
     1                   DIST,TIME,PMARC,SMARC,ANS1,ANS2,ANS3)

      INTEGER  REDAVE(NOA),POIF,SMAVE(NOA),BLUEP1,BLUEP2
      INTEGER  PMARC(5),SMARC(3),ANS1,ANS2,ANS3,ANS4
      REAL     SPEED(NA),DIST(NA),TIME(NA)

1002  WRITE(6,'(///)')
      PRINT *, 'HOW DO RED FORCE ALLOCATE THEIR UNIT ON EACH AVENUE ?'
      PRINT *, '  (CHOOSE THE NUMBER OF OPTION 1,2,3 OR 4)'
      PRINT *, '  *********************************************'
      PRINT *, '  *   OPTION     AVE-#1   AVE-#2   AVE-#3     *'
      PRINT *, '  *     1.        1 BN     1 BN     1 BN      *'
      PRINT *, '  *     2.        0 BN     2 BN     1 BN      *'
      PRINT *, '  *     3.        0 BN     1 BN     2 BN      *'
      PRINT *, '  *     4.        0 BN     3 BN     0 BN      *'
      PRINT *, '  *     0.          EXIT THE RPOGRAM !        *'
      PRINT *, '  *********************************************'
         READ(5,*)  ANS1
      GO TO (1011,1012,1013,1014) ANS1
1011        REDAVE(1) = 1
            REDAVE(2) = 1
            REDAVE(3) = 1
         GO TO 1010
1012        REDAVE(1) = 0
```

```
            REDAVE(2) = 2
            REDAVE(3) = 1
         GO TO 1010
1013        REDAVE(1) = 0
            REDAVE(2) = 1
            REDAVE(3) = 2
         GO TO 1010
1014        REDAVE(1) = 0
            REDAVE(2) = 3
            REDAVE(3) = 0
         GO TO 1010
      IF(ANS1 .EQ. 0) THEN
         GO TO 1999
      ELSE
      PRINT*, '<< ERROR >> : ENTER THE NUMBER 1-4 OR 0 ===> TRY AGAIN !'
         GO TO 1002
      END IF
1010  WRITE(6,'(///)')
      PRINT *, 'HOW DO BLUE FORCE ALLOCATE THE SCATTERABLE MINES ?'
      PRINT *, '  (CHOOSE THE NUMBER OF OPTION 1,2,3 OR 4)'
      PRINT *, '  **************************************************'
      PRINT *, '  *   OPTION     AVE-#1   AVE-#2   AVE-#3     *'
      PRINT *, '  *     1.        1 PKG    1 PKG    1 PKG     *'
      PRINT *, '  *     2.        0 PKG    2 PKG    1 PKG     *'
      PRINT *, '  *     3.        0 PKG    1 PKG    2 PKG     *'
      PRINT *, '  *     4.        0 PKG    3 PKG    0 PKG     *'
      PRINT *, '  *     0.          EXIT THE RPOGRAM !        *'
      PRINT *, '  **************************************************'
         READ(5,*)  ANS2
      GO TO (1031,1032,1033,1034) ANS2
1031        SMAVE(1) = 1
            SMAVE(2) = 1
            SMAVE(3) = 1
         GO TO 1025
1032        SMAVE(1) = 0
            SMAVE(2) = 2
            SMAVE(3) = 1
         GO TO 1025
1033        SMAVE(1) = 0
            SMAVE(2) = 1
            SMAVE(3) = 2
         GO TO 1025
1034        SMAVE(1) = 0
            SMAVE(2) = 3
            SMAVE(3) = 0
         GO TO 1025
      IF(ANS3 .EQ. 0) THEN
         GO TO 1999
      ELSE
      PRINT*, '<< ERROR >> : ENTER THE NUMBER 1-4 OR 0 ===> TRY AGAIN !'
         GO TO 1010
      END IF

1025  WRITE(6,'(///)')
      PRINT *, 'WHICH ARC WILL HAVE SCATTERABLE MINES ? '
      PRINT *, '  ( ENTER THE THREE INDEX NUMBER OF ARCS FROM 1 TO 44)'
```

```
         READ(5,*)  (SMARC(I), I=1,3)
      IF(SMARC(1).GT.44 .OR. SMARC(2).GT.44 .OR. SMARC(3).GT.44) THEN
      PRINT*, '<< ERROR >> : INPUTS MUST BE LESS THAN 44===>TRY AGAIN !'
         GO TO 1025
         ELSE
      WRITE(6,1026) (SMARC(I), I=1,3)
1026  FORMAT(1X,'<< NOTE >> : SCATTERABLE MINES WILL BE ON ',
     1I2,',',I2,',',I2,' ARCS')
      END IF

1020  WRITE(6,'(///)')
      PRINT*, 'HOW DO BLUE FORCE ALLOCATE THEIR UNIT ON EACH POSITION ?'
      PRINT *, '  (CHOOSE THE NUMBER OF OPTION 1 OR 2)'
      PRINT *, '  ****************************************************'
      PRINT *, '  *  OPTION  POSITION#1(NODE28)  POSITION#2(NODE27)  *'
      PRINT *, '  *     1.         2 CO                 1 CO         *'
      PRINT *, '  *     2.         1 CO                 2 CO         *'
      PRINT *, '  *     0.     EXIT THE RPOGRAM !                    *'
      PRINT *, '  ****************************************************'
      READ(5,*)  ANS3
         IF(ANS3 .EQ. 1) THEN
            BLUEP1 = 2
            BLUEP2 = 1
            GO TO 1999
         ELSE IF(ANS3 .EQ. 2) THEN
            BLUEP1 = 1
            BLUEP2 = 2
            GO TO 1999
         ELSE IF(ANS3 .EQ. 0) THEN
            GO TO 1999
         ELSE
      PRINT*, '<< ERROR >> : ENTER THE NUMBER 1,2 OR 0 ===> TRY AGAIN !'
         GO TO 1020
      END IF
1999  RETURN
      END
************************************************************************
*  2. SUBROUTINE FOR DETECTION WHICH ARC THE RED FORCES ARE ?
************************************************************************
      SUBROUTINE  DETECT (IA,IT,INCRE,WHOLD,WID)

      INTEGER  INCRE,WID
      REAL     A1(4),A21(8),A22(6),A3(6),WHOLD

      DATA   A1      /2.75,6.35,9.35,10.25/
      DATA   A21     /1.15,3.3,4.7,5.45,6.4,7.1,8.55,9.45/
      DATA   A22     /1.15,3.3,4.7,6.15,6.8,7.45/
      DATA   A3      /4.5,6.6,8.85,12.35,12.95,13.55/

      GO TO (3011,3012,3013,3014) IA
3011     IF(WHOLD .LE. A1(1)) THEN
            WID = 5
            GO TO 1390
         ELSE IF(WHOLD.GT.A1(1)  .AND.  WHOLD.LE.A1(2)) THEN
            WID = 15
            GO TO 1390
```

```
          ELSE IF(WHOLD.GT.A1(2)  .AND.  WHOLD.LE.A1(3)) THEN
             WID = 33
             GO TO 1390
          ELSE IF(WHOLD.GT.A1(3)  .AND.  WHOLD.LE.A1(4)) THEN
             WID = 35
             GO TO 1390
          ELSE IF(WHOLD .GT.  A1(4)) THEN
       WRITE(13,1380)  IT-1
1380   FORMAT(1X,'RED FORCE IN AVE#1 TOOK BLUE POSITION#1 : BATTLE END !'
     1/5X,'(BATTLE TIME ===> ',I4,' MINUTE)')
       PRINT *, 'RED FORCE IN AVE#1 TOOK BLUE POSITION#1 : BATTLE END !'
       PRINT *, 'BATTLE TIME =',IT-1,' MINUTE'
             GO TO 1399
          END IF
3012      IF(WHOLD .LE.  A21(1)) THEN
             WID = 4
             GO TO 1390
          ELSE IF(WHOLD.GT.A21(1) .AND.  WHOLD.LE.A21(2)) THEN
             WID = 7
             GO TO 1390
          ELSE IF(WHOLD.GT.A21(2) .AND.  WHOLD.LE.A21(3)) THEN
             WID = 19
             GO TO 1390
          ELSE IF(WHOLD.GT.A21(3) .AND.  WHOLD.LE.A21(4)) THEN
             WID = 24
             GO TO 1390
          ELSE IF(WHOLD.GT.A21(4) .AND.  WHOLD.LE.A21(5)) THEN
             WID = 29
             GO TO 1390
          ELSE IF(WHOLD.GT.A21(5) .AND.  WHOLD.LE.A21(6)) THEN
             WID = 32
             GO TO 1390
          ELSE IF(WHOLD.GT.A21(6) .AND.  WHOLD.LE.A21(7)) THEN
             WID = 34
             GO TO 1390
          ELSE IF(WHOLD.GT.A21(7) .AND.  WHOLD.LE.A21(8)) THEN
             WID = 35
             GO TO 1390
          ELSE IF(WHOLD .GT.  A21(8)) THEN
       WRITE(13,1381)  IT-1
1381   FORMAT(1X,'RED FORCE IN AVE#21 TOOK BLUE POSITION#1 : BATTLE ',    '
     1'END !',/5X,'(BATTLE TIME ===> ',I4,' MINUTE)')
       PRINT *, 'RED FORCE IN AVE#21 TOOK BLUE POSITION#1 : BATTLE END !'
       PRINT *, 'BATTLE TIME =',IT-1,' MINUTE'
             GO TO 1399
          END IF
3013      IF(WHOLD .LE.  A22(1)) THEN
             WID = 4
             GO TO 1390
          ELSE IF(WHOLD.GT.A22(1) .AND.  WHOLD.LE.A22(2)) THEN
             WID = 7
             GO TO 1390
          ELSE IF(WHOLD.GT.A22(2) .AND.  WHOLD.LE.A22(3)) THEN
             WID = 19
             GO TO 1390
          ELSE IF(WHOLD.GT.A22(3) .AND.  WHOLD.LE.A22(4)) THEN
```

```
            WID = 25
            GO TO 1390
         ELSE IF(WHOLD.GT.A22(4) .AND. WHOLD.LE.A22(5)) THEN
            WID = 30
            GO TO 1390
         ELSE IF(WHOLD.GT.A22(5) .AND. WHOLD.LE.A22(6)) THEN
            WID = 39
            GO TO 1390
         ELSE IF(WHOLD .GT. A22(6)) THEN
      WRITE(13,1382)  IT-1
1382  FORMAT(1X,'RED FORCE IN AVE#22 TOOK BLUE POSITION#2 : BATTLE ',    '
     1'END ! ',/5X,'(BATTLE TIME ===> ',I4,' MINUTE)')
      PRINT *, 'RED FORCE IN AVE#22 TOOK BLUE POSITION#2 : BATTLE END !'
      PRINT *, 'BATTLE TIME =',IT-1,' MINUTE'
            GO TO 1399
         END IF
3014     IF(WHOLD .LE. A3(1)) THEN
            WID = 2
            GO TO 1390
         ELSE IF(WHOLD.GT.A3(1)  .AND. WHOLD.LE.A3(2)) THEN
            WID = 11
            GO TO 1390
         ELSE IF(WHOLD.GT.A3(2)  .AND. WHOLD.LE.A3(3)) THEN
            WID = 13
            GO TO 1390
         ELSE IF(WHOLD.GT.A3(3)  .AND. WHOLD.LE.A3(4)) THEN
            WID = 23
            GO TO 1390
         ELSE IF(WHOLD.GT.A3(4)  .AND. WHOLD.LE.A3(5)) THEN
            WID = 42
            GO TO 1390
         ELSE IF(WHOLD.GT.A3(5)  .AND. WHOLD.LE.A3(6)) THEN
            WID = 43
            GO TO 1390
         ELSE IF(WHOLD .GT. A3(6)) THEN
      WRITE(13,1383)  IT-1
1383  FORMAT(1X,'RED FORCE IN AVE#3 TOOK BLUE POSITION#2 : BATTLE',
     1' END ! ',/5X,'(BATTLE TIME ===> ',I4,' MINUTE)')
      PRINT *, 'RED FORCE IN AVE#3 TOOK BLUE POSITION#2 : BATTLE END !'
      PRINT *, 'BATTLE TIME =',IT-1,' MINUTE'
            GO TO 1399
         END IF
1390  RETURN
1399  WID = 0
      RETURN
      END
************************************************************************
*  3. SUBROUTINE FOR IDENTIFYING THE INDIRECT-FIRE !
************************************************************************
      SUBROUTINE  IDFIND (IA,CLOCK,POIF,IFANS)
      INTEGER  POIF,IFANS
      REAL     CLOCK,STIF,FTIF
      DATA     STIF,FTIF  /5.0,15.0/

      IF(CLOCK .GE. STIF  .AND.  CLOCK .LT. FTIF) THEN
         IF(POIF .EQ. 2) THEN
```

```
          IF(IA.EQ.2 .OR. IA.EQ.3) THEN
             IFANS = 1
             GO TO 1444
          ELSE
             IFANS = 0
             GO TO 1444
          END IF
       ELSE IF(POIF .EQ. 3) THEN
          IF(IA .EQ. 4) THEN
             IFANS = 1
             GO TO 1444
          ELSE
             IFANS = 0
             GO TO 1444
          END IF
       END IF
    ELSE
       IFANS = 0
    END IF
1444 RETURN
    END
*******************************************************************
*  4. SUBROUTINE FOR IDENTIFYING THE MINE-FIELD !
*******************************************************************
    SUBROUTINE  MFFIND (PMARC,SMARC,WID,MFANS)
    INTEGER  MFANS,WID,PMARC(5),SMARC(3)

    DO 1510 I = 1,5
       IF(WID .EQ. PMARC(I)) THEN
          MFANS = 1
          GO TO 1599
       END IF
1510 CONTINUE
1511 DO 1520 J = 1,3
       IF(WID .EQ. SMARC(J)) THEN
          MFANS = 2
          GO TO 1599
       END IF
1520 CONTINUE
1521 MFANS = 0
1599 RETURN
    END
*******************************************************************
*  5. SUBROUTINE FOR IDENTIFYING THE DIRECT-FIRE !
*******************************************************************
    SUBROUTINE  DRFIND (IA,WHOLD,RANGE,BRDIST,DFANS)

    INTEGER  IC,IA,DFANS
    REAL     WHOLD,PATH(4),RANGE,BRDIST,AMBUSH

    DATA     PATH   /10.25,9.45,7.45,13.55/
    DATA     AMBUSH /4.0/

       IF(WHOLD .GE. AMBUSH-RANGE/2.   .AND.
   1      WHOLD .LT. AMBUSH            .AND.
   1     (IA.EQ.2. .OR. IA.EQ.3))       THEN
```

```
               DFANS = 1
               BRDIST = AMBUSH - WHOLD
               GO TO 1699
         ELSE IF( WHOLD .GE. PATH(IA)-RANGE  .AND.
     1            WHOLD .LT. PATH(IA)       )  THEN
               DFANS = 2
               BRDIST = PATH(IA) - WHOLD
               GO TO 1699
         END IF
1600  CONTINUE
      DFANS = 0
1699  RETURN
      END
******************************************************************
*  6. SUBROUTINE FOR COMPUTING CASUALTIES BY INDIRECT-FIRE
******************************************************************
      SUBROUTINE IDFIRE(IA,IT,RF,REDAVE,POIF,IFCAS)
      INTEGER  NROUND,IA,IT,REDAVE(3),POIF
      REAL     LETHAL,ROWSP,COLSP,MUX,MUY,RHOX,RHOY,RATIO,PKILL
      REAL     RF(4,0:1001),IFCAS

      DATA   NROUND,LETHAL  /18,70.8/
      DATA   MUX,MUY        /15.,10./
      DATA   RHOX,RHOY      /15.,10./

      IF(REDAVE(POIF) .EQ. 1)  THEN
         ROWSP = 12.
         COLSP = 12.
         GO TO 1669
      ELSE IF(REDAVE(POIF) .EQ. 2)  THEN
         ROWSP = 10.
         COLSP = 10.
         GO TO 1669
      ELSE IF(REDAVE(POIF) .EQ. 3)  THEN
         ROWSP =  8.
         COLSP =  8.
         GO TO 1669
      END IF

1669  RATIO = (NROUND*LETHAL) / (ROWSP*COLSP*RF(IA,IT))
      PHI = 3.141592654
      A = ((LETHAL*NROUND)/(2*PHI))**.5
      PKILL = RATIO * (A*A/((A*A+RHOX**2)*(A*A+RHOY**2))**.5) *
     1       EXP(-.5*((MUX**2)/(A*A+RHOX**2) + (MUY**2)/(A*A+RHOY**2)))
      IFCAS = PKILL * RF(IA,IT) / 2.
      RETURN
      END
******************************************************************
*  7. SUBROUTINE FOR COMPUTING CASUALTIES BY MINEFIELDS
******************************************************************
      SUBROUTINE MFIELD (IA,IT,MFANS,INCRE,NA,WID,TIME,RF,MFCAS)

      INTEGER  MFANS,INCRE,NA,NOPM,NOSM,WID
      REAL     TIME(NA),RF(4,0:1001),PCOEF,SCOEF,MFCAS,TPM,TSM

      DATA     NOPM ,NOSM   /300,200/
      DATA     TPM  ,TSM    /20.0,15.0/
      DATA     PCOEF,SCOEF  /.00020,.00015/

      IF(MFANS .EQ. 1) THEN
         MFCAS = (PCOEF*RF(IA,IT)*NOPM*(TPM/60.)) / (TIME(WID)/INCRE)
      ELSE IF(MFANS .EQ. 2) THEN
         MFCAS = (SCOEF*RF(IA,IT)*NOSM*(TSM/60.)) / (TIME(WID)/INCRE)
      END IF
      RETURN
      END
******************************************************************
*  8. SUBROUTINE FOR COMPUTING CASUALTIES BY DIRECT FIRE
******************************************************************
      SUBROUTINE DRFIRE(DFANS,DFA,BRDIST,IA,IT,RF,BF,AR,RDFCAS,BDFCAS,
     1                  PLTN,RANGE,NNN,ACO,AMO)
      INTEGER  DFANS,DFA(4,1000),PLTN
      REAL     RF(4,0:1001),BF(4,0:1001),PLBP,FBF(0:1001)
      REAL     BRDIST,RANGE,RED,BLU,RDFCAS,BDFCAS,AR,BR,MU,PL

      DATA     PLBP           / 0.0/
      DATA     AOMEGA,BOMEGA  /0.50,1.00/
      DATA     AC,BC          /0.0380,0.0160/
      DATA     AM,BM          /0.23,0.00010/
      DATA     MU             /1.0/

      ACO = AC
      AMO = AM
      IF(NNN .GT. 0)  GO TO 1810
      PL = PLTN
1810  FBF(IT) = PL
C---FIND ENGAGED FORCES OF BOTH SIDES ON DIRECT FIRE BATTLE !
      RED = RF(IA,IT)
      BLU = BF(IA,IT)

C---CASE-#1 (MIXED LAW) : BLUE FORCE AMBUSHES THE RED FORCE !
      IF(DFANS .EQ. 1) THEN
         AR = AM * (1.0-BRDIST/RANGE)**MU
         BR = BM * (1.0-BRDIST/RANGE)**MU
         BLU = FBF(IT)
         IF(BLU .LT. PLBP)  THEN
            RDFCAS = 0.0
            BLU = 0.0
         ELSE
            RDFCAS = AR * BLU
         END IF
         BDFCAS = BR * BLU * RED
         FBF(IT) = BLU - BDFCAS
         PL = FBF(IT)
         NNN = NNN + 1
         GO TO 1900

C---CASE-#2 (HEMBOLT EQUTION) !
      ELSE IF(DFANS .EQ. 2) THEN
         IF(RED .LE. 0.  .OR.  BLU .LE. 0.)  THEN
            BDFCAS = 0.
            RDFCAS = 0.
            GO TO 1900
         END IF
         AR = AC * (1.0-BRDIST/RANGE)**MU
         BR = BC * (1.0-BRDIST/RANGE)**MU
         RDFCAS = AR*((RED/BLU)**(1.0-BOMEGA))*BLU
         BDFCAS = BR*((BLU/RED)**(1.0-AOMEGA))*RED
      END IF
1900  RETURN
      END
*****************************************************************
*  9. SUBROUTINE FOR COMPUTING THE ADJUSTED SPEED !
*****************************************************************
      SUBROUTINE  ASPEED (I,NA,ANS1,SPEED,ADSP)

      INTEGER  ANS1,AOA1(4),AOA2(3),AOA3(6)
      REAL     SPEED(NA),ADSP(NA)

      DATA     AOA1        /5,15,33,35/
      DATA     AOA2        /4,7,19/
      DATA     AOA3        /2,11,13,23,42,43/

         GO TO (201,202,203,204)  ANS1
201         ADSP(I) = SPEED(I)
            GO TO 2010
202         ADSP(I) = SPEED(I)
            DO 2011 J = 1,3
2011           IF(I .EQ. AOA2(J))  ADSP(I) = 0.9*SPEED(I)
            GO TO 2010
203         ADSP(I) = SPEED(I)
            DO 2012 J = 1,6
2012           IF(I .EQ. AOA3(J))  ADSP(I) = 0.9*SPEED(I)
            GO TO 2010
204         ADSP(I) = SPEED(I)
            DO 2013 J = 1,3
2013           IF(I .EQ. AOA2(J))  ADSP(I) = 0.8*SPEED(I)

2010  RETURN
      END
*****************************************************************
* 10. SUBROUTINE FOR COMPUTING THE REDUCED SPEED !
*****************************************************************
      SUBROUTINE  RSPEED (IA,IT,NA,SPEED,TIME,DIST,WID,RANGE,AR,RF,
     1                    IFANS,MFANS,DFANS,OSPEED,ACO,AMO)

      INTEGER  NA,WID,IFANS,MFANS,DFANS
      REAL     AR,DIST(NA),SPEED(NA),TIME(NA),MINSPD,RF(4,0:1001)
      REAL     OSPEED(NA)

      DATA     MINSPD    /0.500/

      IF(IFANS .EQ. 1) THEN
         SPEED(WID) = DIST(WID)*60./(TIME(WID)+10.)
      END IF
      IF(MFANS .EQ. 1)  THEN
         SPEED(WID) = DIST(WID)*60./(TIME(WID)+20.)
      END IF
      IF(MFANS .EQ. 2)  THEN
         SPEED(WID) = DIST(WID)*60./(TIME(WID)+15.)
      END IF
      IF(DFANS .EQ. 1) THEN
         SPEED(WID) = SPEED(WID) * (1.0-AR/AMO) + MINSPD
         IF(SPEED(WID) .GT. OSPEED(WID))  SPEED(WID) = OSPEED(WID)
      END IF
      IF(DFANS .EQ. 2) THEN
         IF(RF(IA,IT) .EQ. 0.) THEN
            SPEED(WID) = 0.
         ELSE
            SPEED(WID) = SPEED(WID) * (1.0-AR/ACO) + MINSPD
            IF(SPEED(WID) .GT. OSPEED(WID))  SPEED(WID) = OSPEED(WID)
         END IF
      END IF
      RETURN
      END
************************************************************************
* 11. TO FIND THE TIME AND LOCATION WHEN RED FORCE REACH BREAK-POINT !
************************************************************************
      SUBROUTINE  BREAK (IA,IT,NOC,WHOLD,RF,BF,RRESER,BREAKP,BREAKT)

      INTEGER RRESER
      REAL    BREAKP(4),BREAKT(4),WHOLD,RF(4,0:1001),BF(4,0:1001)

      RF(IA,IT) = 0.
      BF(IA,IT) = BF(IA,IT-1)
         IF(NOC .EQ. 0)  THEN
C           RF(IA,IT) = RF(IA,IT-1) + RRESER
            BREAKP(IA) = WHOLD
            BREAKT(IA) = IT
         END IF
      NOC = NOC + 1
1111  RETURN
      END
************************************************************************
* 12. TO PRINT THE CASUALTIES AND SURVIVORS FOR BOTH SIDES !
************************************************************************
      SUBROUTINE  PRINT (RBN,BCO,BLUEP1,BLUEP2,RRESER,PLTN,NA,OUTPUT,
     1                    IFSUM,MFSUM,RDFSUM,BDFSUM)

      INTEGER  RBN,BCO,BLUEP1,BLUEP2,NA,RRESER,PLTN,OUTPUT
      REAL     IFSUM(4),MFSUM(4),RDFSUM(4),BDFSUM(4)
      REAL     TIFSUM,TMFSUM,TRDF,TBDF
      CHARACTER*9  AVENUE(4)
      DATA   AVENUE   /'AVENUE#1','AVENUE#21','AVENUE#22','AVENUE#3'/
      DATA   TIFSUM,TMFSUM,TRDF,TBDF     /4*0.0/

      WRITE(OUTPUT,'(//)')
      WRITE(OUTPUT,100)
100   FORMAT(5X,'<<< RED CASUALTIES BY EACH TYPE OF BLUE FORCES >>>',
     1/60('-'),
     1/15X,'INDIRECT-FIRE',4X,'MINE-FIELD',4X,'DIRECT-FIRE',/60('-'))
      DO 101 IA = 1,4
         TIFSUM = IFSUM(IA) + TIFSUM
         TMFSUM = MFSUM(IA) + TMFSUM
         TRDF = RDFSUM(IA) + TRDF
         TBDF = BDFSUM(IA) + TBDF
         WRITE(OUTPUT,102) AVENUE(IA),IFSUM(IA),MFSUM(IA),RDFSUM(IA)
101   CONTINUE
      WRITE(OUTPUT,103) TIFSUM,TMFSUM,TRDF
102   FORMAT(3X,A9,5X,F6.1,10X,F6.1,9X,F6.1)
103   FORMAT(60('-'),/17X,F6.1,10X,F6.1,9X,F6.1)
      TRF = RBN*3.0 + RRESER
      TBF = BCO*3.0 + PLTN
      TRCAS = TIFSUM + TMFSUM + TRDF
      TRSUR = TRF - TRCAS
      TBCAS = TBDF
      TBSUR = TBF - TBCAS
      BFCAS1 = BDFSUM(1) + BDFSUM(2)
      BFCAS2 = BDFSUM(3) + BDFSUM(4)
      BFSUR1 = BLUEP1*BCO + PLTN/2 - BFCAS1
      BFSUR2 = BLUEP2*BCO + PLTN/2 - BFCAS2

      WRITE(OUTPUT,'(//)')
      WRITE(OUTPUT,105) BFCAS1,BFSUR1,BFCAS2,BFSUR2
105   FORMAT(5X,'<<< BLUE FORCE CASUALTIES FOR EACH FORT >>>',
     1/60('-'),/15X,'CASUALTIES',5X,'SURVIVORS',/60('-'),/3X,'FORT#1',
     15X,F6.1,10X,F6.1,/3X,'FORT#2',5X,F6.1,10X,F6.1,/60('-'))
      WRITE(OUTPUT,'(//)')
      WRITE(OUTPUT,106) TRF,TRCAS,TRSUR,TBF,TBCAS,TBSUR
106   FORMAT(5X,'<<< TOTAL CASUALTIES AND SURVIVORS >>>',
     1/60('-'),/13X,'INITIAL FORCE',5X,'CASUALTIES',6X,
     1'SURVIVORS',/60('-'),/5X,'RED',9X,F6.1,10X,F6.1,10X,F6.1,
     1/5X,'BLUE',8X,F6.1,10X,F6.1,10X,F6.1,/60('-'))

      RETURN
      END
```

APPENDIX C. EXEC FOR BASIC MODEL

This is a execution code of Fortran-77 for the basic model in Appendix B.

```
FILEDEF 12 DISK THESIS DATA
EXEC WF77 BASIC (NOEXT NOWAR
```

APPENDIX D. ADVANCED MODEL

This is a computer program using Fortran-77 for the advanced model.

```
C
C ---< ADVANCED MODEL >--- MADE BY   LEE, JAE YEONG (1988.2.6) ---
C
      INTEGER  MR,MB
      PARAMETER  (MR=4, MB=8)
      REAL     RED(MR,MB),BLUE(MR,MB),BATIME(MR,MB),ROB(MR,MB)
      INTEGER  ANSWER,REDAVE(3),POIF,SMAVE(3),BLUEP1,BLUEP2,SMARC(3)
      INTEGER  OUTPUT,TEND,WAVE2
      INTEGER  ARC(44),TAIL(44),HEAD(44)
      REAL     DIST(44),WIDTH(44),SPEED(44),TIME(44),OSPEED(44),ADSP(44)
      REAL     TRCAS,TBSUR,TBCAS,VALUE(4)
      REAL     LINE(MB),SQUA(MB),ROOT(MB),LIN,SQU,ROO
777   WRITE(6,'(///)')
      PRINT *, 'HOW DO RED FORCES ON AVENUE-2 ATTACK ?'
      PRINT *, '*****************************************************************'
      PRINT *, '* <OPTION>                 < EXPLANATION >                      *'
      PRINT *, '*    1      ALL FORCES ATTACK TO THE NODE 28                    *'
      PRINT *, '*    2      ALL FORCES ATTACK TO THE NODE 27                    *'
      PRINT *, '*    3      DIVIDE EQUALLY AND ATTACK TO NODE 27 AND            *'
      PRINT *, '*             NODE 28, RESPECTIVELY                             *'
      PRINT *, '*    0      EXIT THE PROGRAM !                                  *'
      PRINT *, '*****************************************************************'
         READ(5,*) ANSWER
      IF (ANSWER .EQ.  0) GO TO 888
      IF (ANSWER.NE.1 .AND.  ANSWER.NE.2 .AND.
     1    ANSWER.NE.3 .AND.  ANSWER.NE.0      ) GO TO 777

      GO TO (55,56,57)  ANSWER
55       WAVE2 = 1
         GO TO 58
56       WAVE2 = 2
         GO TO 58
57       WAVE2 = 12
         GO TO 58

58    INPUT = 12
      OUTPUT = 24

C---OPEN OUTPUT FILES !
C---FILE 'MOES2' HAS ALL MOE VALUES FOR EACH RED AND BLUE OPTIONS.
C---FILE 'UTIL2' HAS UTILITY VALUES FOR EACH UTILITY FUNCTION.
C---FILE 'WHOW2' REPRESENTS HOW THE BATTLE TERMINATES!
      OPEN ( UNIT = OUTPUT, FILE = 'MOES2' )
      OPEN ( UNIT = 25    , FILE = 'UTIL2' )
      OPEN ( UNIT = 26    , FILE = 'WHOW2' )

      DO 1 IB = 1,MB
         CALL  BDATA (IB,WAVE2,POIF,SMAVE,BLUEP1,BLUEP2,SMARC)
         DO 2 IR = 1,MR
            CALL  RDATA (IR,REDAVE)

            DO 10 I = 1, 44
               READ(INPUT,11) ARC(I),TAIL(I),HEAD(I),TIME(I),DIST(I),
     1                        WIDTH(I),SPEED(I)

               CALL ASPED1 (WAVE2,I,IR,SPEED,ADSP)
               IF(WAVE2 .EQ. 12)  CALL ASPED2 (I,IR,SPEED,ADSP)
                  SPEED(I) = ADSP(I)
                  OSPEED(I) = SPEED(I)
10          CONTINUE
11          FORMAT(3X,I2,2(3X,I2),2X,F6.2,6X,F4.2,4X,F5.3,3X,F3.1)

C--- READ THE ORIGINAL DATA AGAIN ! ------------------------------------
            REWIND  INPUT
C----------------------------------------------------------------------

            IF(WAVE2 .EQ. 1  .OR.  WAVE2 .EQ. 2)  THEN
               CALL  BATLE1 (WAVE2,TRCAS,TBSUR,TEND,TBCAS,
     1               IB,IR,REDAVE,POIF,SMAVE,BLUEP1,BLUEP2,SMARC,
     1               ARC,TAIL,HEAD,TIME,DIST,WIDTH,SPEED,OSPEED)
            ELSE IF(WAVE2 .EQ. 12)  THEN
               CALL  BATLE2 (TRCAS,TBSUR,TEND,TBCAS,
     1               IB,IR,REDAVE,POIF,SMAVE,BLUEP1,BLUEP2,SMARC,
     1               ARC,TAIL,HEAD,TIME,DIST,WIDTH,SPEED,OSPEED)
            END IF

            RED(IR,IB) = TRCAS
            BLUE(IR,IB) = TBSUR
            BATIME(IR,IB) = TEND
            ROB(IR,IB) = TRCAS/TBCAS
            DO 4 I = 1,44
4              SPEED(I) = OSPEED(I)

2        CONTINUE

      WRITE(OUTPUT,900)  IB,RED(1,IB),RED(2,IB),RED(3,IB),RED(4,IB),
     1      IB,BLUE(1,IB),BLUE(2,IB),BLUE(3,IB),BLUE(4,IB),
     1      IB,BATIME(1,IB),BATIME(2,IB),BATIME(3,IB),BATIME(4,IB),
     1      IB,ROB(1,IB),ROB(2,IB),ROB(3,IB),ROB(4,IB)
900   FORMAT( 3X,I3,4(3X,F6.1),/3X,I3,4(3X,F6.1),/3X,I3,4(3X,F6.1),
     1       /3X,I3,4(3X,F6.2) )

         DO 905 J = 1,4
905         VALUE(J) = BLUE(J,IB)

C---COMPUTE DESIRED VALUES FOR DIFERRENT UTILITY FUNCTIONS !
         CALL  UTIL (MR,MB,IB,VALUE,LIN,SQU,ROO)

            LINE(IB) = LIN
            SQUA(IB) = SQU
            ROOT(IB) = ROO
      WRITE(25,910)  IB,LINE(IB),SQUA(IB),ROOT(IB)
910   FORMAT( 3X,I3,3(3X,F6.2) )

1     CONTINUE

888   STOP   'THIS MODEL IS COMPLETE !   THANK YOU !'
      END

*******************************************************************************
*  I. SUBROUTINE FOR DEFINING RED OPTIONS.
*******************************************************************************
      SUBROUTINE RDATA (IR,REDAVE)
      INTEGER  IR,REDAVE(3)

      GO TO (1151,1152,1153,1154)  IR
1151     REDAVE(1) = 1
         REDAVE(2) = 1
         REDAVE(3) = 1
         GO TO 1155
1152     REDAVE(1) = 0
         REDAVE(2) = 2
         REDAVE(3) = 1
         GO TO 1155
1153     REDAVE(1) = 0
         REDAVE(2) = 1
         REDAVE(3) = 2
         GO TO 1155
1154     REDAVE(1) = 0
         REDAVE(2) = 3
         REDAVE(3) = 0
         GO TO 1155
1155  RETURN
      END
*******************************************************************************
* II. SUBROUTINE FOR DEFINING BLUE OPTIONS.
*******************************************************************************
      SUBROUTINE BDATA (IB,WAVE2,POIF,SMAVE,BLUEP1,BLUEP2,SMARC)

      INTEGER  IB,WAVE2,POIF,SMAVE(3),BLUEP1,BLUEP2,SMARC(3)
      IIB = IB
      IF(IB .LE. 4) THEN
         BLUEP1 = 1
         BLUEP2 = 2
         GO TO 1250
      ELSE
         BLUEP1 = 2
         BLUEP2 = 1
         IB = IB - 4
      END IF

1250  GO TO (1251,1252,1253,1254)  IB
1251     POIF = 2
         SMAVE(1) = 1
         SMAVE(2) = 1
         SMAVE(3) = 1
         SMARC(1) = 30
```

```
        SMARC(2) = 35
        SMARC(3) = 42
           IF(WAVE2 .EQ. 1) THEN
              SMARC(1) = 30
              SMARC(2) = 34
              SMARC(3) = 42
           ELSE IF(WAVE2 .EQ. 2) THEN
              SMARC(1) = 35
              SMARC(2) = 39
              SMARC(3) = 42
           END IF
        GO TO 1267
1252    POIF = 2
        SMAVE(1) = 0
        SMAVE(2) = 2
        SMAVE(3) = 1
        SMARC(1) = 30
        SMARC(2) = 34
        SMARC(3) = 42
           IF(WAVE2 .EQ. 1) THEN
              SMARC(1) = 34
              SMARC(2) = 35
              SMARC(3) = 42
           ELSE IF(WAVE2 .EQ. 2) THEN
              SMARC(1) = 30
              SMARC(2) = 39
              SMARC(3) = 42
           END IF
        GO TO 1267
1253    POIF = 2
        SMAVE(1) = 0
        SMAVE(2) = 1
        SMAVE(3) = 2
        SMARC(1) = 30
        SMARC(2) = 42
        SMARC(3) = 43
           IF(WAVE2 .EQ. 1) THEN
              SMARC(1) = 35
              SMARC(2) = 42
              SMARC(3) = 43
           ELSE IF(WAVE2 .EQ. 2) THEN
              SMARC(1) = 39
              SMARC(2) = 42
              SMARC(3) = 43
           END IF
        GO TO 1267
1254    POIF = 2
        SMAVE(1) = 0
        SMAVE(2) = 3
        SMAVE(3) = 0
        SMARC(1) = 30
        SMARC(2) = 34
        SMARC(3) = 35
           IF(WAVE2 .EQ. 1) THEN
              SMARC(1) = 32
              SMARC(2) = 34
```

```
               SMARC(3) = 35
            ELSE IF(WAVE2 .EQ. 2) THEN
               SMARC(1) = 25
               SMARC(2) = 30
               SMARC(3) = 39
            END IF
         GO TO 1267
1267  IB = IIB
      RETURN
      END

************************************************************************
* III. SUBROUTINE TO EXECUTE THE "BATTLE1" TYPE BATTLE !
************************************************************************
C
C     THIS PROGRAM DEAL WITH THE BATTLE CASE THAT HAS 3 AVENUES OF
C   APPROACH FOR RED FORCES CONTINUEOUSLY.  (I.E., RED FORCES ON AVENUE-2
C   ATTACK TO JUST ONE OF TWO BLUE POSITIONS).
C
      SUBROUTINE  BATLE1 (WAVE2,TRCAS,TBSUR,TEND,TBCAS,
     1                    IB,IR,REDAVE,POIF,SMAVE,BLUEP1,BLUEP2,SMARC,
     1                    ARC,TAIL,HEAD,TIME,DIST,WIDTH,SPEED,OSPEED)
      INTEGER    NA, NN, NOA, NOP, RBN, RRESER, BCO, PLTN
      PARAMETER (NA=44, NN=28, NOA=3, NOP=2, PLTN=40)
      PARAMETER (RBN=500, RRESER=150, BCO=170)
      INTEGER    REDAVE(NOA),SMAVE(NOA),PMAVE(NOA)
      INTEGER    ARC(NA),TAIL(NA),HEAD(NA)
      INTEGER    PMARC(5),SMARC(3),IDARC(3,0:1001)
      INTEGER    IFA(3,1000),MFA(3,1000),DFA(3,1000)
      INTEGER    POIF,BLUEP1,BLUEP2,ANS1,ANS2,ANS3,ANS4
      INTEGER    INPUT,OUTPUT,TP1,TP2,DIF,DPMF,DSMF,INCRE,WID
      INTEGER    IFANS,MFANS,DFANS,TEND,WAVE2
      REAL     DIST(NA),WIDTH(NA),TIME(NA),SPEED(NA),OSPEED(NA)
      REAL     BREAKP(3),BREAKT(3),RBP(3)
      REAL     RF(3,0:1001),BF(3,0:1001),WHERE(3,0:1001),SP(3,0:1001)
      REAL     IFC(3,0:1001),MFC(3,0:1001),RDFC(3,0:1001),
     1         IMDC(3,0:1001),BDFC(3,0:1001)
      REAL     IFSUM(3),MFSUM(3),RDFSUM(3),BDFSUM(3)
      REAL     IFCAS,MFCAS,DFCAS,BLEFT1,BLEFT2,WHOLD
      REAL     CLOCK,RANGE,BRDIST,AR,RB

      DATA   DIF,DPMF,DSMF  /10,20,15/
      DATA   PMAVE          /1,3,1/
      DATA   PMARC          /15,19,23,25,32/
      DATA   RANGE          /1.1/
      DATA   RB             /0.0/

      ANS1 = IR
      NNN = 0
      IUSED = 0
      NEQ12 = 0
      NEQ23 = 0

C---DEFINE INITIAL FORCE LEVEL AND LOCATION !
27    DO 28 I = 1,NOA
         RF(I,0) = REDAVE(I)*RBN
         WHERE(I,0) = 0.0
         IFC(I,0) = 0.0
         MFC(I,0) = 0.0
         RDFC(I,0) = 0.0
         IMDC(I,0) = 0.0
         BDFC(I,0) = 0.0
         IFSUM(I) = 0.0
         MFSUM(I) = 0.0
         RDFSUM(I) = 0.0
         BDFSUM(I) = 0.0
28       RBP(I) = RB*RF(I,0)

      IF(WAVE2 .EQ. 1)  THEN
         BF(1,0) = BLUEP1*BCO + PLTN
         BF(2,0) = BLUEP1*BCO + PLTN
         BF(3,0) = BLUEP2*BCO
      ELSE IF(WAVE2 .EQ. 2)  THEN
         BF(1,0) = BLUEP1*BCO
         BF(2,0) = BLUEP2*BCO + PLTN
         BF(3,0) = BLUEP2*BCO + PLTN
      END IF

      NOC = 0
      INCRE = 1
      DO 9999 IT = 1,500,INCRE

      CLOCK = IT
      DO 30 IA = 1,NOA

         BREAKP(IA) = 0.0
         BREAKT(IA) = 0.0
            IFC(IA,IT) = IFC(IA,IT-1)
            MFC(IA,IT) = MFC(IA,IT-1)
            RDFC(IA,IT) = RDFC(IA,IT-1)
            IMDC(IA,IT) = IMDC(IA,IT-1)
            BDFC(IA,IT) = BDFC(IA,IT-1)
         RF(IA,IT) = RF(IA,IT-1)
         BF(IA,IT) = BF(IA,IT-1)
         WHOLD = WHERE(IA,IT-1)
         CALL  DETET1 (WAVE2,IA,IT,INCRE,WHOLD,WID)
            IF(WID .EQ. 0)  GO TO 999
         IDARC(IA,IT) = WID
         BRDIST = 9999.
         SP(IA,IT) = SPEED(WID)
         TS = (SPEED(WID)/60)*INCRE
         WHERE(IA,IT) = WHOLD + TS

C---IS THERE INDIRECT FIRE ? OR MINEFIELD ? OR DIRECT FIRE ?
            CALL  IDFND1 (IA,CLOCK,POIF,IFANS)
            CALL  MFFND1 (PMARC,SMARC,WID,MFANS)
            CALL  DRFND1 (WAVE2,IA,WHOLD,RANGE,BRDIST,DFANS)

         IFA(IA,IT) = IFANS
         MFA(IA,IT) = MFANS
         DFA(IA,IT) = DFANS
```

```
        IF(IFANS.EQ.0 .AND. MFANS.EQ.0 .AND. DFANS.EQ.0)  GO TO 30

C---COMPUTE THE CASUALTY OF INDIRECT-FIRE !
        IF(IFANS .EQ. 1) THEN
           CALL  IDFIR1 (IA,IT,RF,REDAVE,POIF,IFCAS)
           RF(IA,IT) = RF(IA,IT) - IFCAS
           IFSUM(IA) = IFCAS + IFSUM(IA)
           IFC(IA,IT) = IFC(IA,IT) + IFCAS
        END IF

C---COMPUTE THE CASUALTY BY MINE-FIELD !
        IF(MFANS.EQ.1  .OR.  MFANS.EQ.2) THEN
           CALL  MFILD1 (IA,IT,MFANS,INCRE,NA,WID,TIME,RF,MFCAS)
           RF(IA,IT) = RF(IA,IT) - MFCAS
           MFSUM(IA) = MFCAS + MFSUM(IA)
           MFC(IA,IT) = MFC(IA,IT) + MFCAS
        END IF

C---COMPUTE THE CASUALTY BY DIRECT-FIRE !
        IF(DFANS .EQ. 1  .OR.  DFANS .EQ. 2) THEN
           IF( RF(IA,IT) .LT. BF(IA,IT)    .AND.
     1         IUSED .EQ. 0                .AND.
     1         RF(IA,0) .GT. 0.0         )  THEN
              RF(IA,IT) = RF(IA,IT) + RRESER
              IUSED = 1
           END IF
           CALL  DRFIR1 (DFANS,DFA,BRDIST,IA,IT,RF,BF,AR,RDFCAS,BDFCAS,
     1                   PLTN,RANGE,NNN)

           RF(IA,IT) = RF(IA,IT) - RDFCAS
           BF(IA,IT) = BF(IA,IT) - BDFCAS
           RDFSUM(IA) = RDFCAS + RDFSUM(IA)
           BDFSUM(IA) = BDFCAS + BDFSUM(IA)
           RDFC(IA,IT) = RDFC(IA,IT) + RDFCAS
           BDFC(IA,IT) = BDFC(IA,IT) + BDFCAS
        END IF

        IF(RF(IA,0) .GT. 0.  .AND.  RF(IA,IT) .LE. RBP(IA)) THEN
           CALL  BREAK1 (IA,IT,NOC,WHOLD,RF,BF,RRESER,BREAKP,BREAKT)
        END IF

C---COMPUTE THE REDUCED SPEED DUE TO THE INDIRECT FIRE OR MINEFIELD OR
C   UNDER THE DIRECT FIRE BASED ON THE RANGE OF TWO FORCES !

           CALL  RSPED1 (IA,IT,NA,SPEED,TIME,DIST,WID,RANGE,AR,RF,
     1                   IFANS,MFANS,DFANS,OSPEED)

        SP(IA,IT) = SPEED(WID)
        TS = (SPEED(WID)/60)*INCRE
        WHERE(IA,IT) = WHOLD + TS
        IMDC(IA,IT) = IFC(IA,IT) + MFC(IA,IT) + RDFC(IA,IT)

30    CONTINUE

      IF(WAVE2 .EQ. 1)  THEN
         IF(NEQ12 .NE. 0)  GO TO 9999
         BF(1,IT) = MIN( BF(1,IT),BF(2,IT) )
         BF(2,IT) = MIN( BF(1,IT),BF(2,IT) )
         BF(3,IT) = BF(3,IT)
         IF(DFA(1,IT) .EQ. 2  .AND.  DFA(2,IT) .EQ. 2  .AND.
     1      RF(1,IT) .GT. 0.  .AND.  RF(2,IT) .GT. 0.)  THEN
            BF(1,IT) = (RF(1,IT) / (RF(1,IT)+RF(2,IT))) * BF(1,IT)
            BF(2,IT) = (RF(1,IT) / (RF(1,IT)+RF(2,IT))) * BF(2,IT)
            BF(3,IT) = BF(3,IT)
            NEQ12 = IT
         END IF
      ELSE IF(WAVE2 .EQ. 2)  THEN
         IF(NEQ23 .NE. 0)  GO TO 9999
         BF(1,IT) = BF(1,IT)
         BF(2,IT) = MIN( BF(2,IT),BF(3,IT) )
         BF(3,IT) = MIN( BF(2,IT),BF(3,IT) )
         IF(DFA(1,IT) .EQ. 2  .AND.  DFA(2,IT) .EQ. 2  .AND.
     1      RF(1,IT) .GT. 0.  .AND.  RF(2,IT) .GT. 0.)  THEN
            BF(1,IT) = BF(1,IT)
            BF(2,IT) = (RF(2,IT) / (RF(2,IT)+RF(3,IT))) * BF(2,IT)
            BF(3,IT) = (RF(3,IT) / (RF(2,IT)+RF(3,IT))) * BF(3,IT)
            NEQ23 = IT
         END IF
      END IF

9999  CONTINUE

999      CALL  PRINT1 (RBN,BCO,BLUEP1,BLUEP2,RRESER,PLTN,NA,
     1                WAVE2,IFSUM,MFSUM,RDFSUM,BDFSUM,
     1                TRCAS,TBCAS,TRSUR,TBSUR)

      TEND = IT - 1
      RETURN
      END
***********************************************************************
* III-1. SUBROUTINE FOR LOCATING THE ARC THE RED FORCES ARE ATTACKING.
***********************************************************************
      SUBROUTINE  DETET1 (WAVE2,IA,IT,INCRE,WHOLD,WID)

      INTEGER  INCRE,WID,WAVE2
      REAL     A1(4),A21(8),A22(8),A3(6),WHOLD

      DATA   A1      /2.75,6.35,9.35,10.25/
      DATA   A21     /1.15,3.3,4.7,5.45,6.4,7.1,8.55,9.45/
      DATA   A22     /1.15,3.3,4.7,6.15,6.8,7.45,7.45,7.45/
      DATA   A3      /4.5,6.6,8.85,12.35,12.95,13.55/

      IF(IA .EQ. 1) THEN
         IF(WHOLD .LE. A1(1)) THEN
            WID = 5
            GO TO 1390
         ELSE IF(WHOLD.GT.A1(1)  .AND.  WHOLD.LE.A1(2)) THEN
            WID = 15
            GO TO 1390
         ELSE IF(WHOLD.GT.A1(2)  .AND.  WHOLD.LE.A1(3)) THEN
            WID = 33
            GO TO 1390
         ELSE IF(WHOLD.GT.A1(3)  .AND. WHOLD.LE.A1(4)) THEN
            WID = 35
            GO TO 1390
         ELSE IF(WHOLD .GT. A1(4)) THEN
      WRITE(26,1380)  IT-1
1380  FORMAT(1X,'RED FORCE IN AVE#1 TOOK BLUE POSITION#1 : BATTLE END !'
     1/5X,'(BATTLE TIME ===> ',I4,' MINUTE)')
            GO TO 1399
         END IF
      ELSE IF(IA .EQ. 2) THEN
         GO TO (1311,1312) WAVE2
1311     IF(WHOLD .LE. A21(1)) THEN
            WID = 4
            GO TO 1390
         ELSE IF(WHOLD.GT.A21(1) .AND. WHOLD.LE.A21(2)) THEN
            WID = 7
            GO TO 1390
         ELSE IF(WHOLD.GT.A21(2) .AND. WHOLD.LE.A21(3)) THEN
            WID = 19
            GO TO 1390
         ELSE IF(WHOLD.GT.A21(3) .AND. WHOLD.LE.A21(4)) THEN
            WID = 24
            GO TO 1390
         ELSE IF(WHOLD.GT.A21(4) .AND. WHOLD.LE.A21(5)) THEN
            WID = 29
            GO TO 1390
         ELSE IF(WHOLD.GT.A21(5) .AND. WHOLD.LE.A21(6)) THEN
            WID = 32
            GO TO 1390
         ELSE IF(WHOLD.GT.A21(6) .AND. WHOLD.LE.A21(7)) THEN
            WID = 34
            GO TO 1390
         ELSE IF(WHOLD.GT.A21(7) .AND. WHOLD.LE.A21(8)) THEN
            WID = 35
            GO TO 1390
         ELSE IF(WHOLD .GT. A21(8)) THEN
      WRITE(26,1381)  IT-1
1381  FORMAT(1X,'RED FORCE IN AVE#21 TOOK BLUE POSITION#1 : BATTLE ',    '
     1'END !',/5X,'(BATTLE TIME ===> ',I4,' MINUTE)')
            GO TO 1399
         END IF
1312     IF(WHOLD .LE. A22(1)) THEN
            WID = 4
            GO TO 1390
         ELSE IF(WHOLD.GT.A22(1) .AND. WHOLD.LE.A22(2)) THEN
            WID = 7
            GO TO 1390
         ELSE IF(WHOLD.GT.A22(2) .AND. WHOLD.LE.A22(3)) THEN
            WID = 19
            GO TO 1390
         ELSE IF(WHOLD.GT.A22(3) .AND. WHOLD.LE.A22(4)) THEN
            WID = 25
            GO TO 1390
         ELSE IF(WHOLD.GT.A22(4) .AND. WHOLD.LE.A22(5)) THEN
            WID = 30
            GO TO 1390
         ELSE IF(WHOLD.GT.A22(5) .AND. WHOLD.LE.A22(6)) THEN
            WID = 39
            GO TO 1390
         ELSE IF(WHOLD .GT. A22(6)) THEN
      WRITE(26,1382)  IT-1
1382  FORMAT(1X,'RED FORCE IN AVE#22 TOOK BLUE POSITION#2 : BATTLE ',    '
     1'END !',/5X,'(BATTLE TIME ===> ',I4,' MINUTE)')
            GO TO 1399
         END IF
      ELSE IF(IA .EQ. 3) THEN
         IF(WHOLD .LE. A3(1)) THEN
            WID = 2
            GO TO 1390
         ELSE IF(WHOLD.GT.A3(1)  .AND. WHOLD.LE.A3(2)) THEN
            WID = 11
            GO TO 1390
         ELSE IF(WHOLD.GT.A3(2)  .AND. WHOLD.LE.A3(3)) THEN
            WID = 13
            GO TO 1390
         ELSE IF(WHOLD.GT.A3(3)  .AND. WHOLD.LE.A3(4)) THEN
            WID = 23
            GO TO 1390
         ELSE IF(WHOLD.GT.A3(4)  .AND. WHOLD.LE.A3(5)) THEN
            WID = 42
            GO TO 1390
         ELSE IF(WHOLD.GT.A3(5)  .AND. WHOLD.LE.A3(6)) THEN
            WID = 43
            GO TO 1390
         ELSE IF(WHOLD .GT. A3(6)) THEN
      WRITE(26,1383)  IT-1
1383  FORMAT(1X,'RED FORCE IN AVE#3 TOOK BLUE POSITION#2 : BATTLE',
     1' END !',/5X,'(BATTLE TIME ===> ',I4,' MINUTE)')
            GO TO 1399
         END IF
      END IF
1390  RETURN
1399  WID = 0
      RETURN
      END
**********************************************************************
* III-2. SUBROUTINE FOR IDENTIFYING THE INDIRECT-FIRE !
**********************************************************************
      SUBROUTINE  IDFND1 (IA,CLOCK,POIF,IFANS)
      INTEGER  POIF,IFANS
      REAL     CLOCK,STIF,FTIF
      DATA     STIF,FTIF  /5.0,15.0/

      IF(CLOCK .GE. STIF  .AND.  CLOCK .LT. FTIF) THEN
         IF(IA .EQ. 2)  THEN
            IFANS = 1
            GO TO 1444
         ELSE
            IFANS = 0
            GO TO 1444
         END IF
      ELSE
```

```
         IFANS = 0
      END IF
1444  RETURN
      END
************************************************************************
* III-3. SUBROUTINE FOR IDENTIFYING THE MINE-FIELD !
************************************************************************
      SUBROUTINE  MFFND1 (PMARC,SMARC,WID,MFANS)
      INTEGER  MFANS,WID,PMARC(5),SMARC(3)

      DO 1510 I = 1,5
         IF(WID .EQ. PMARC(I)) THEN
            MFANS = 1
            GO TO 1599
         END IF
1510  CONTINUE
1511  DO 1520 J = 1,3
         IF(WID .EQ. SMARC(J)) THEN
            MFANS = 2
            GO TO 1599
         END IF
1520  CONTINUE
1521  MFANS = 0
1599  RETURN
      END
************************************************************************
* III-4. SUBROUTINE FOR IDENTIFYING THE DIRECT-FIRE !
************************************************************************
      SUBROUTINE  DRFND1 (WAVE2,IA,WHOLD,RANGE,BRDIST,DFANS)

      INTEGER  IA,DFANS,WAVE2
      REAL     WHOLD,PATH(3),RANGE,BRDIST,AMBUSH

      DATA     AMBUSH   /4.0/
               PATH(1) = 10.25
               PATH(2) =  9.45
                  IF(WAVE2 .EQ. 2)  PATH(2) = 7.45
               PATH(3) = 13.55

         IF(WHOLD .GE. AMBUSH-RANGE/2.  .AND.
     1      WHOLD .LT. AMBUSH           .AND.
     1      IA    .EQ. 2               )  THEN
               DFANS = 1
               BRDIST = AMBUSH - WHOLD
               GO TO 1699
         ELSE IF( WHOLD .GE. PATH(IA)-RANGE  .AND.
     1            WHOLD .LT. PATH(IA)       )  THEN
               DFANS = 2
               BRDIST = PATH(IA) - WHOLD
               GO TO 1699
         END IF
      DFANS = 0
1699  RETURN
      END
************************************************************************
```

```
* III-5. SUBROUTINE FOR COMPUTING CASUALTIES BY INDIRECT-FIRE
************************************************************************
      SUBROUTINE IDFIR1(IA,IT,RF,REDAVE,POIF,IFCAS)
      INTEGER  NROUND,IA,IT,REDAVE(3),POIF
      REAL     LETHAL,ROWSP,COLSP,MUX,MUY,RHOX,RHOY,RATIO,PKILL
      REAL     RF(3,0:1001),IFCAS

      DATA   NROUND,LETHAL  /18,70.8/
      DATA   MUX,MUY        /15.,10./
      DATA   RHOX,RHOY      /15.,10./

      IF(REDAVE(POIF) .EQ. 1)  THEN
         ROWSP = 12.
         COLSP = 12.
         GO TO 1669
      ELSE IF(REDAVE(POIF) .EQ. 2)  THEN
         ROWSP = 10.
         COLSP = 10.
         GO TO 1669
      ELSE IF(REDAVE(POIF) .EQ. 3)  THEN
         ROWSP =  8.
         COLSP =  8.
         GO TO 1669
      END IF
      PRINT *, IT,IA,RF(IA,IT)
1669  RATIO = (NROUND*LETHAL) / (ROWSP*COLSP*RF(IA,IT))
      PHI = 3.141592654
      A = ((LETHAL*NROUND)/(2*PHI))**.5
      PKILL = RATIO * (A*A/((A*A+RHOX**2)*(A*A+RHOY**2))**.5) *
     1       EXP(-.5*((MUX**2)/(A*A+RHOX**2) + (MUY**2)/(A*A+RHOY**2)))
      IFCAS = PKILL * RF(IA,IT)
      RETURN
      END
************************************************************************
* III-6. SUBROUTINE FOR COMPUTING CASUALTIES BY MINEFIELDS
************************************************************************
      SUBROUTINE MFILD1(IA,IT,MFANS,INCRE,NA,WID,TIME,RF,MFCAS)

      INTEGER  MFANS,INCRE,NA,NOPM,NOSM,WID
      REAL     TIME(NA),RF(3,0:1001),PCOEF,SCOEF,MFCAS,TPM,TSM

      DATA     NOPM ,NOSM   /300,200/
      DATA     TPM  ,TSM    /20.0,15.0/
      DATA     PCOEF,SCOEF  /.00020,.00015/

      IF(MFANS .EQ. 1) THEN
         MFCAS = (PCOEF*RF(IA,IT)*NOPM*(TPM/60.)) / (TIME(WID)/INCRE)
      ELSE IF(MFANS .EQ. 2) THEN
         MFCAS = (SCOEF*RF(IA,IT)*NOSM*(TSM/60.)) / (TIME(WID)/INCRE)
      END IF
      RETURN
      END
************************************************************************
* III-7. SUBROUTINE FOR COMPUTING CASUALTIES BY DIRECT FIRE
************************************************************************
      SUBROUTINE DRFIR1(DFANS,DFA,BRDIST,IA,IT,RF,BF,AR,RDFCAS,BDFCAS,
     1                  PLTN,RANGE,NNN)
      INTEGER  DFANS,DFA(3,1000),PLTN
      REAL     RF(3,0:1001),BF(3,0:1001),PLBP,FBF(0:1001)
      REAL     BRDIST,RANGE,RED,BLU,RDFCAS,BDFCAS,AR,BR,MU,PL

      DATA     PLBP           /10.0/
      DATA     AOMEGA,BOMEGA  /0.50,1.00/
      DATA     AC,BC          /0.0490,0.0250/
      DATA     AM,BM          /0.23,0.00010/
      DATA     MU             /1.0/

      IF(NNN .GT. 0)  GO TO 1810
      PL = PLTN
1810  FBF(IT) = PL
C---FIND ENGAGED FORCES OF BOTH SIDES ON DIRECT FIRE BATTLE !
      RED = RF(IA,IT)
      BLU = BF(IA,IT)

C---CASE-#1 (MIXED LAW) : BLUE FORCE AMBUSHES THE RED FORCE !
      IF(DFANS .EQ. 1) THEN
         AR = AM * (1-BRDIST/RANGE)**MU
         BR = BM * (1-BRDIST/RANGE)**MU
         BLU = FBF(IT)
         IF(BLU .LT. PLBP)  THEN
            RDFCAS = 0.0
            BLU = 0.0
         ELSE
            RDFCAS = AR * BLU
         END IF
         BDFCAS = BR * BLU * RED
         FBF(IT) = BLU - BDFCAS
         PL = FBF(IT)
         NNN = NNN + 1
         GO TO 1900

C---CASE-#2 (HEMBOLT EQUTION) !
      ELSE IF(DFANS .EQ. 2) THEN
         IF(RED .LE. 0.   .OR.  BLU .LE. 0.)  THEN
            BDFCAS = 0.
            RDFCAS = 0.
            GO TO 1900
         END IF
         AR = AC * (1-BRDIST/RANGE)**MU
         BR = BC * (1-BRDIST/RANGE)**MU
         RDFCAS = AR*((RED/BLU)**(1.0-BOMEGA))*BLU
         BDFCAS = BR*((BLU/RED)**(1.0-AOMEGA))*RED
      END IF
1900  RETURN
      END
*****************************************************************
* III-8. SUBROUTINE FOR COMPUTING THE ADJUSTED SPEED BASED ON
*        THE NUMBER OF RED UNITS (BATTALIONS) ON EACH AVENUE.
*****************************************************************
      SUBROUTINE  ASPED1(WAVE2,I,IR,SPEED,ADSP)

      INTEGER  WAVE2,IR,AOA1(4),AOA2(8),AOA3(6),AOA21(8),AOA22(8)
      REAL     SPEED(44),ADSP(44)

      DATA     AOA1        /5,15,33,35/
      DATA     AOA21       /4,7,19,24,29,32,34,35/
      DATA     AOA22       /4,7,19,25,30,39,39,39/
      DATA     AOA3        /2,11,13,23,42,43/

         DO 2009 K = 1,8
            AOA2(K) = AOA21(K)
2009        IF(WAVE2 .EQ. 2)   AOA2(K) = AOA22(K)

         GO TO (201,202,203,204)  IR
201         ADSP(I) = SPEED(I)
            GO TO 2010
202         ADSP(I) = SPEED(I)
            DO 2011 J = 1,8
2011           IF(I .EQ. AOA2(J))  ADSP(I) = 0.9*SPEED(I)
            GO TO 2010
203         ADSP(I) = SPEED(I)
            DO 2012 J = 1,6
2012           IF(I .EQ. AOA3(J))  ADSP(I) = 0.9*SPEED(I)
            GO TO 2010
204         ADSP(I) = SPEED(I)
            DO 2013 J = 1,3
2013           IF(I .EQ. AOA2(J))  ADSP(I) = 0.8*SPEED(I)

2010  RETURN
      END
*****************************************************************
* III-9. SUBROUTINE FOR COMPUTING THE REDUCED SPEED BASED ON
*        EACH WEAPON TYPE.
*****************************************************************
      SUBROUTINE  RSPED1(IA,IT,NA,SPEED,TIME,DIST,WID,RANGE,AR,RF,
     1                     IFANS,MFANS,DFANS,OSPEED)

      INTEGER  NA,WID,IFANS,MFANS,DFANS
      REAL     AR,DIST(NA),SPEED(NA),TIME(NA),MINSPD,RF(3,0:1001)
      REAL     OSPEED(NA)

      DATA     MINSPD    /0.5/
      DATA     ACO,AMO   /0.06,0.20/

      IF(IFANS .EQ. 1) THEN
         SPEED(WID) = DIST(WID)*60./(TIME(WID)+10.)
      END IF
      IF(MFANS .EQ. 1)  THEN
         SPEED(WID) = DIST(WID)*60./(TIME(WID)+20.)
      END IF
      IF(MFANS .EQ. 2)  THEN
         SPEED(WID) = DIST(WID)*60./(TIME(WID)+15.)
      END IF
      IF(DFANS .EQ. 1) THEN
         SPEED(WID) = SPEED(WID) * (1-AR/AMO) + MINSPD
         IF(SPEED(WID) .GT. OSPEED(WID))  SPEED(WID) = OSPEED(WID)
      END IF
      IF(DFANS .EQ. 2) THEN
```

```
         IF(RF(IA,IT) .EQ. 0.) THEN
            SPEED(WID) = 0.
         ELSE
            SPEED(WID) = SPEED(WID) * (1-AR/ACO) + MINSPD
            IF(SPEED(WID) .GT. OSPEED(WID))  SPEED(WID) = OSPEED(WID)
         END IF
      END IF
      RETURN
      END
***********************************************************************
* III-10. SUBROUTINE TO FIND THE TIME AND LOCATION
*         WHEN RED FORCE REACH BREAK-POINT !
***********************************************************************
      SUBROUTINE  BREAK1 (IA,IT,NOC,WHOLD,RF,BF,RRESER,BREAKP,BREAKT)

      INTEGER RRESER
      REAL    BREAKP(3),BREAKT(3),WHOLD,RF(3,0:1001),BF(3,0:1001)

      RF(IA,IT) = 0.
      BF(IA,IT) = BF(IA,IT-1)
         IF(NOC .EQ. 0)  THEN
C           RF(IA,IT) = RF(IA,IT-1) + RRESER
            BREAKP(IA) = WHOLD
            BREAKT(IA) = IT
         END IF
      NOC = NOC + 1
1111  RETURN
      END
***********************************************************************
* III-11. SUBROUTINE TO PRINT THE CASUALTIES AND SURVIVORS
*         FOR BOTH SIDES IN BATTLE1 TYPE.
***********************************************************************
      SUBROUTINE  PRINT1 (RBN,BCO,BLUEP1,BLUEP2,RRESER,PLTN,NA,
     1                   WAVE2,IFSUM,MFSUM,RDFSUM,BDFSUM,
     1                   TRCAS,TBCAS,TRSUR,TBSUR)

      INTEGER  RBN,BCO,BLUEP1,BLUEP2,NA,RRESER,PLTN,WAVE2
      REAL     IFSUM(3),MFSUM(3),RDFSUM(3),BDFSUM(3)
      REAL     TIFSUM,TMFSUM,TRDF,TBDF
      REAL     TRCAS,TRSUR,TBCAS,TBSUR

      TIFSUM = 0.0
      TMFSUM = 0.0
      TRDF = 0.0
      TBDF = 0.0

      TRCAS = 0.0
      TBCAS = 0.0
      TRSUR = 0.0
      TBSUR = 0.0

      DO 101 IA = 1,3
         TIFSUM = IFSUM(IA) + TIFSUM
         TMFSUM = MFSUM(IA) + TMFSUM
         TRDF = RDFSUM(IA) + TRDF
         TBDF = BDFSUM(IA) + TBDF
101   CONTINUE
      TRF = RBN*3.0 + RRESER
      TBF = BCO*3.0 + PLTN
      TRCAS = TIFSUM + TMFSUM + TRDF
      TRSUR = TRF - TRCAS
      TBCAS = TBDF
      TBSUR = TBF - TBCAS
      IF(WAVE2 .EQ. 1)  THEN
         BFCAS1 = BDFSUM(1) + BDFSUM(2)
         BFCAS2 = BDFSUM(3)
         BFSUR1 = BLUEP1*BCO + PLTN - BFCAS1
         BFSUR2 = BLUEP2*BCO - BFCAS2
      ELSE IF(WAVE2 .EQ. 2)  THEN
         BFCAS1 = BDFSUM(1)
         BFCAS2 = BDFSUM(2) + BDFSUM(3)
         BFSUR1 = BLUEP1*BCO - BFCAS1
         BFSUR2 = BLUEP2*BCO + PLTN - BFCAS2
      END IF

      TRCAS = TIFSUM + TMFSUM + TRDF
      TRSUR = TRF - TRCAS
      TBCAS = TBDF
      TBSUR = TBF - TBCAS

      RETURN
      END
************************************************************************
* IV. SUBROUTINE TO EXECUTE THE "BATTLE2" TYPE BATTLE.
************************************************************************
C
C     THIS PROGRAM DEAL WITH THE BATTLE CASE THAT HAS 3 AVENUES OF
C   APPROACH FOR RED FORCES INITIALLY, BUT ATTACK TO BLUE WITH 4 AVENUES
C   OF APPROACH FINALLY.  (I.E., RED FORCES ON AVENUE-2 DIVIDE EQUALLY
C   AND ATTACK TO BOTH BLUE POSITIONS : NODE 27 AND NODE 28).
C
      SUBROUTINE  BATLE2 (TRCAS,TBSUR,TEND,TBCAS,
     1                    IB,IR,REDAVE,POIF,SMAVE,BLUEP1,BLUEP2,SMARC,
     1                    ARC,TAIL,HEAD,TIME,DIST,WIDTH,SPEED,OSPEED)
      INTEGER    NA, NN, NOA, NOP, RBN, RRESER, BCO, PLTN
      PARAMETER (NA=44, NN=28, NOA=3, NOP=2, PLTN=40)
      PARAMETER (RBN=500, RRESER=150, BCO=170)
      INTEGER    REDAVE(NOA),SMAVE(NOA),PMAVE(NOA)
      INTEGER    ARC(NA),TAIL(NA),HEAD(NA)
      INTEGER    PMARC(5),SMARC(3),IDARC(4,0:1001)
      INTEGER    IFA(4,1000),MFA(4,1000),DFA(4,1000)
      INTEGER    POIF,BLUEP1,BLUEP2,ANS1,ANS2,ANS3,ANS4
      INTEGER    INPUT,OUTPUT,TP1,TP2,DIF,DPMF,DSMF,INCRE,WID
      INTEGER    IFANS,MFANS,DFANS,TEND
      REAL     DIST(NA),WIDTH(NA),TIME(NA),SPEED(NA),OSPEED(NA)
      REAL     BREAKP(4),BREAKT(4),RBP(4)
      REAL     RF(4,0:1001),BF(4,0:1001),WHERE(4,0:1001),SP(4,0:1001)
      REAL     IFC(4,0:1001),MFC(4,0:1001),RDFC(4,0:1001),
     1         IMDC(4,0:1001),BDFC(4,0:1001)
      REAL     IFSUM(4),MFSUM(4),RDFSUM(4),BDFSUM(4)
      REAL     IFCAS,MFCAS,DFCAS,BLEFT1,BLEFT2,WHOLD
      REAL     CLOCK,RANGE,BRDIST,AR,RB

      DATA   DIF,DPMF,DSMF  /10,20,15/
      DATA   PMAVE          /1,3,1/
      DATA   PMARC          /15,19,23,25,32/
      DATA   RANGE          /1.1/
      DATA   RB             /0.0/

      ANS1 = IR
      NNN = 0
      IUSED = 0
      NEQ12 = 0
      NEQ34 = 0
      DO 5 I = 1,4
         IFSUM(I) = 0.0
         MFSUM(I) = 0.0
         RDFSUM(I) = 0.0
         BDFSUM(I) = 0.0
5     CONTINUE
C---DEFINE INITIAL FORCE LEVEL AND LOCATION !
      RF(1,0) = REDAVE(1)*RBN
      RF(2,0) = (REDAVE(2)*RBN)/2
      RF(3,0) = (REDAVE(2)*RBN)/2
      RF(4,0) = REDAVE(3)*RBN
      DO 28 I = 1,4
         WHERE(I,0) = 0.
         IFC(I,0) = 0.
         MFC(I,0) = 0.
         RDFC(I,0) = 0.
         IMDC(I,0) = 0.
         BDFC(I,0) = 0.
28       RBP(I) = RB*RF(I,0)
      BF(1,0) = BLUEP1*BCO + PLTN/2
      BF(2,0) = BLUEP1*BCO + PLTN/2
      BF(3,0) = BLUEP2*BCO + PLTN/2
      BF(4,0) = BLUEP2*BCO + PLTN/2

      NOC = 0
      INCRE = 1
      DO 9999 IT = 1,500,INCRE

      CLOCK = IT
      DO 30 IA = 1,4

         BREAKP(IA) = 0.0
         BREAKT(IA) = 0.0
            IFC(IA,IT) = IFC(IA,IT-1)
            MFC(IA,IT) = MFC(IA,IT-1)
            RDFC(IA,IT) = RDFC(IA,IT-1)
            IMDC(IA,IT) = IMDC(IA,IT-1)
            BDFC(IA,IT) = BDFC(IA,IT-1)
         RF(IA,IT) = RF(IA,IT-1)
         BF(IA,IT) = BF(IA,IT-1)
         WHOLD = WHERE(IA,IT-1)
         CALL  DETET2(IA,IT,INCRE,WHOLD,WID)
            IF(WID .EQ. 0)  GO TO 999
         IDARC(IA,IT) = WID
         BRDIST = 9999.
         SP(IA,IT) = SPEED(WID)
         TS = (SPEED(WID)/60)*INCRE
         WHERE(IA,IT) = WHOLD + TS

C---IS THERE INDIRECT FIRE ? OR MINEFIELD ? OR DIRECT FIRE ?
            CALL  IDFND2 (IA,CLOCK,POIF,IFANS)
            CALL  MFFND2 (PMARC,SMARC,WID,MFANS)
            CALL  DRFND2 (IA,WHOLD,RANGE,BRDIST,DFANS)

         IFA(IA,IT) = IFANS
         MFA(IA,IT) = MFANS
         DFA(IA,IT) = DFANS

         IF(IFANS.EQ.0 .AND.  MFANS.EQ.0 .AND.  DFANS.EQ.0)  GO TO 30

C---COMPUTE THE CASUALTY OF INDIRECT-FIRE !
         IF(IFANS .EQ. 1) THEN
            CALL  IDFIR2 (IA,IT,RF,REDAVE,POIF,IFCAS)
            RF(IA,IT) = RF(IA,IT) - IFCAS
            IFSUM(IA) = IFCAS + IFSUM(IA)
            IFC(IA,IT) = IFC(IA,IT) + IFCAS
         END IF

C---COMPUTE THE CASUALTY BY MINE-FIELD !
         IF(MFANS.EQ.1  .OR.  MFANS.EQ.2) THEN
            CALL  MFILD2 (IA,IT,MFANS,INCRE,NA,WID,TIME,RF,MFCAS)
            RF(IA,IT) = RF(IA,IT) - MFCAS
            MFSUM(IA) = MFCAS + MFSUM(IA)
            MFC(IA,IT) = MFC(IA,IT) + MFCAS
         END IF

C---COMPUTE THE CASUALTY BY DIRECT-FIRE !
         IF(DFANS .EQ. 1  .OR.  DFANS .EQ. 2) THEN
            IF( RF(IA,IT) .LT. BF(IA,IT)    .AND.
     1          IUSED .EQ.  0                .AND.
     1          RF(IA,0) .GT.  0.0         )  THEN
                   RF(IA,IT) = RF(IA,IT) + RRESER
                   IUSED = 1
            END IF
            CALL  DRFIR2 (DFANS,DFA,BRDIST,IA,IT,RF,BF,AR,RDFCAS,BDFCAS,
     1                    PLTN,RANGE,NNN,ACO,AMO)

            RF(IA,IT) = RF(IA,IT) - RDFCAS
            BF(IA,IT) = BF(IA,IT) - BDFCAS
            RDFSUM(IA) = RDFCAS + RDFSUM(IA)
            BDFSUM(IA) = BDFCAS + BDFSUM(IA)
            RDFC(IA,IT) = RDFC(IA,IT) + RDFCAS
            BDFC(IA,IT) = BDFC(IA,IT) + BDFCAS
         END IF

         IF(RF(IA,0) .GT. 0.  .AND.  RF(IA,IT) .LE. RBP(IA)) THEN
            CALL  BREAK2 (IA,IT,NOC,WHOLD,RF,BF,RRESER,BREAKP,BREAKT)
         END IF
```

```
C---COMPUTE THE REDUCED SPEED DUE TO THE INDIRECT FIRE OR MINEFIELD OR
C   UNDER THE DIRECT FIRE BASED ON THE RANGE OF TWO FORCES !

            CALL  RSPED2 (IA,IT,NA,SPEED,TIME,DIST,WID,RANGE,AR,RF,
     1                     IFANS,MFANS,DFANS,OSPEED,ACO,AMO)

         SP(IA,IT) = SPEED(WID)
         TS = (SPEED(WID)/60)*INCRE
         WHERE(IA,IT) = WHOLD + TS
         IMDC(IA,IT) = IFC(IA,IT) + MFC(IA,IT) + RDFC(IA,IT)

30    CONTINUE

      IF(NEQ12 .NE. 0)  GO TO 36
         BF(1,IT) = MIN( BF(1,IT),BF(2,IT) )
         BF(2,IT) = MIN( BF(1,IT),BF(2,IT) )
36    IF(NEQ34 .NE. 0)  GO TO 37
         BF(3,IT) = MIN( BF(3,IT),BF(4,IT) )
         BF(4,IT) = MIN( BF(3,IT),BF(4,IT) )
37    IF(NEQ12 .NE. 0)  GO TO 38
      IF(DFA(1,IT) .EQ. 2  .AND.  DFA(2,IT) .EQ. 2  .AND.
     1   RF(1,IT) .GT. 0.  .AND.  RF(2,IT) .GT. 0.)  THEN
            BF(1,IT) = (RF(1,IT) / (RF(1,IT)+RF(2,IT))) * BF(1,IT)
            BF(2,IT) = (RF(2,IT) / (RF(1,IT)+RF(2,IT))) * BF(2,IT)
            NEQ12 = IT
      END IF
38    IF(NEQ34 .NE. 0)  GO TO 9999
      IF(DFA(3,IT) .EQ. 2  .AND.  DFA(4,IT) .EQ. 2  .AND.
     1   RF(3,IT) .GT. 0.  .AND.  RF(4,IT) .GT. 0.)  THEN
            BF(3,IT) = (RF(3,IT) / (RF(3,IT)+RF(4,IT))) * BF(3,IT)
            BF(4,IT) = (RF(4,IT) / (RF(3,IT)+RF(4,IT))) * BF(4,IT)
            NEQ34 = IT
      END IF

9999  CONTINUE

999      CALL  PRINT2 (RBN,BCO,BLUEP1,BLUEP2,RRESER,PLTN,NA,
     1                 IFSUM,MFSUM,RDFSUM,BDFSUM,
     1                 TRCAS,TBCAS,TRSUR,TBSUR)

      TEND = IT - 1
      RETURN
      END
************************************************************************
* IV-1. SUBROUTINE FOR LOCATING THE ARC THE RED FORCES ARE ATTACKING.
************************************************************************
      SUBROUTINE  DETET2 (IA,IT,INCRE,WHOLD,WID)

      INTEGER  INCRE,WID
      REAL     A1(4),A21(8),A22(6),A3(6),WHOLD

      DATA   A1      /2.75,6.35,9.35,10.25/
      DATA   A21     /1.15,3.3,4.7,5.45,6.4,7.1,8.55,9.45/
      DATA   A22     /1.15,3.3,4.7,6.15,6.8,7.45/
      DATA   A3      /4.5,6.6,8.85,12.35,12.95,13.55/
      GO TO (3011,3012,3013,3014) IA
3011     IF(WHOLD .LE. A1(1)) THEN
            WID = 5
            GO TO 1390
         ELSE IF(WHOLD.GT.A1(1)  .AND.  WHOLD.LE.A1(2)) THEN
            WID = 15
            GO TO 1390
         ELSE IF(WHOLD.GT.A1(2)  .AND.  WHOLD.LE.A1(3)) THEN
            WID = 33
            GO TO 1390
         ELSE IF(WHOLD.GT.A1(3)  .AND.  WHOLD.LE.A1(4)) THEN
            WID = 35
            GO TO 1390
         ELSE IF(WHOLD .GT.  A1(4)) THEN
      WRITE(26,1380)  IT-1
1380  FORMAT(1X,'RED FORCE IN AVE#1 TOOK BLUE POSITION#1 : BATTLE END !'
     1/5X,'(BATTLE TIME ===> ',I4,' MINUTE)')
            GO TO 1399
         END IF
3012     IF(WHOLD .LE.  A21(1)) THEN
            WID = 4
            GO TO 1390
         ELSE IF(WHOLD.GT.A21(1) .AND.  WHOLD.LE.A21(2)) THEN
            WID = 7
            GO TO 1390
         ELSE IF(WHOLD.GT.A21(2) .AND.  WHOLD.LE.A21(3)) THEN
            WID = 19
            GO TO 1390
         ELSE IF(WHOLD.GT.A21(3) .AND.  WHOLD.LE.A21(4)) THEN
            WID = 24
            GO TO 1390
         ELSE IF(WHOLD.GT.A21(4) .AND.  WHOLD.LE.A21(5)) THEN
            WID = 29
            GO TO 1390
         ELSE IF(WHOLD.GT.A21(5) .AND.  WHOLD.LE.A21(6)) THEN
            WID = 32
            GO TO 1390
         ELSE IF(WHOLD.GT.A21(6) .AND.  WHOLD.LE.A21(7)) THEN
            WID = 34
            GO TO 1390
         ELSE IF(WHOLD.GT.A21(7) .AND.  WHOLD.LE.A21(8)) THEN
            WID = 35
            GO TO 1390
         ELSE IF(WHOLD .GT.  A21(8)) THEN
      WRITE(26,1381)  IT-1
1381  FORMAT(1X,'RED FORCE IN AVE#21 TOOK BLUE POSITION#1 :  BATTLE ',
     1'END !',/5X,'(BATTLE TIME ===> ',I4,' MINUTE)')
            GO TO 1399
         END IF
3013     IF(WHOLD .LE.  A22(1)) THEN
            WID = 4
            GO TO 1390
         ELSE IF(WHOLD.GT.A22(1) .AND.  WHOLD.LE.A22(2)) THEN
            WID = 7
            GO TO 1390
         ELSE IF(WHOLD.GT.A22(2) .AND.  WHOLD.LE.A22(3)) THEN
```

```
            WID = 19
            GO TO 1390
         ELSE IF(WHOLD.GT.A22(3) .AND. WHOLD.LE.A22(4)) THEN
            WID = 25
            GO TO 1390
         ELSE IF(WHOLD.GT.A22(4) .AND. WHOLD.LE.A22(5)) THEN
            WID = 30
            GO TO 1390
         ELSE IF(WHOLD.GT.A22(5) .AND. WHOLD.LE.A22(6)) THEN
            WID = 39
            GO TO 1390
         ELSE IF(WHOLD .GT. A22(6)) THEN
      WRITE(26,1382)  IT-1
1382  FORMAT(1X,'RED FORCE IN AVE#22 TOOK BLUE POSITION#2 : BATTLE ',    '
     1'END !',/5X,'(BATTLE TIME ===> ',I4,' MINUTE)')
            GO TO 1399
         END IF
3014     IF(WHOLD .LE. A3(1)) THEN
            WID = 2
            GO TO 1390
         ELSE IF(WHOLD.GT.A3(1)  .AND. WHOLD.LE.A3(2)) THEN
            WID = 11
            GO TO 1390
         ELSE IF(WHOLD.GT.A3(2)  .AND. WHOLD.LE.A3(3)) THEN
            WID = 13
            GO TO 1390
         ELSE IF(WHOLD.GT.A3(3)  .AND. WHOLD.LE.A3(4)) THEN
            WID = 23
            GO TO 1390
         ELSE IF(WHOLD.GT.A3(4)  .AND. WHOLD.LE.A3(5)) THEN
            WID = 42
            GO TO 1390
         ELSE IF(WHOLD.GT.A3(5)  .AND. WHOLD.LE.A3(6)) THEN
            WID = 43
            GO TO 1390
         ELSE IF(WHOLD .GT. A3(6)) THEN
      WRITE(26,1383)  IT-1
1383  FORMAT(1X,'RED FORCE IN AVE#3 TOOK BLUE POSITION#2 : BATTLE',
     1' END !',/5X,'(BATTLE TIME ===> ',I4,' MINUTE)')
            GO TO 1399
         END IF
1390  RETURN
1399  WID = 0
      RETURN
      END
******************************************************************
* IV-2. SUBROUTINE FOR IDENTIFYING THE INDIRECT-FIRE !
******************************************************************
      SUBROUTINE  IDFND2 (IA,CLOCK,POIF,IFANS)
      INTEGER  POIF,IFANS
      REAL     CLOCK,STIF,FTIF
      DATA     STIF,FTIF  /5.0,15.0/

      IF(CLOCK .GE. STIF  .AND.  CLOCK .LT. FTIF) THEN
         IF(POIF .EQ. 2) THEN
            IF(IA.EQ.2 .OR. IA.EQ.3) THEN
```

```
               IFANS = 1
               GO TO 1444
            ELSE
               IFANS = 0
               GO TO 1444
            END IF
         ELSE IF(POIF .EQ. 3) THEN
            IF(IA .EQ. 4) THEN
               IFANS = 1
               GO TO 1444
            ELSE
               IFANS = 0
               GO TO 1444
            END IF
         END IF
      ELSE
         IFANS = 0
      END IF
1444  RETURN
      END
*****************************************************************
* IV-3. SUBROUTINE FOR IDENTIFYING THE MINE-FIELD !
*****************************************************************
      SUBROUTINE  MFFND2 (PMARC,SMARC,WID,MFANS)
      INTEGER  MFANS,WID,PMARC(5),SMARC(3)

      DO 1510 I = 1,5
         IF(WID .EQ. PMARC(I)) THEN
            MFANS = 1
            GO TO 1599
         END IF
1510  CONTINUE
1511  DO 1520 J = 1,3
         IF(WID .EQ. SMARC(J)) THEN
            MFANS = 2
            GO TO 1599
         END IF
1520  CONTINUE
1521  MFANS = 0
1599  RETURN
      END
*****************************************************************
* IV-4. SUBROUTINE FOR IDENTIFYING THE DIRECT-FIRE !
*****************************************************************
      SUBROUTINE  DRFND2 (IA,WHOLD,RANGE,BRDIST,DFANS)

      INTEGER  IC,IA,DFANS
      REAL     WHOLD,PATH(4),RANGE,BRDIST,AMBUSH

      DATA     PATH   /10.25,9.45,7.45,13.55/
      DATA     AMBUSH /4.0/

         IF(WHOLD .GE. AMBUSH-RANGE/2.   .AND.
     1      WHOLD .LT. AMBUSH            .AND.
     1     (IA.EQ.2.  .OR.  IA.EQ.3))     THEN
               DFANS = 1
            BRDIST = AMBUSH - WHOLD
            GO TO 1699
         ELSE IF( WHOLD .GE. PATH(IA)-RANGE  .AND.
     1             WHOLD .LT. PATH(IA)      )  THEN
            DFANS = 2
            BRDIST = PATH(IA) - WHOLD
            GO TO 1699
         END IF
1600  CONTINUE
      DFANS = 0
1699  RETURN
      END
**********************************************************************
* IV-5. SUBROUTINE FOR COMPUTING CASUALTIES BY INDIRECT-FIRE
**********************************************************************
      SUBROUTINE IDFIR2 (IA,IT,RF,REDAVE,POIF,IFCAS)
      INTEGER  NROUND,IA,IT,REDAVE(3),POIF
      REAL     LETHAL,ROWSP,COLSP,MUX,MUY,RHOX,RHOY,RATIO,PKILL
      REAL     RF(4,0:1001),IFCAS

      DATA   NROUND,LETHAL  /18,70.8/
      DATA   MUX,MUY        /15.,10./
      DATA   RHOX,RHOY      /15.,10./

      IF(REDAVE(POIF) .EQ. 1)  THEN
         ROWSP = 12.
         COLSP = 12.
         GO TO 1669
      ELSE IF(REDAVE(POIF) .EQ. 2)  THEN
         ROWSP = 10.
         COLSP = 10.
         GO TO 1669
      ELSE IF(REDAVE(POIF) .EQ. 3)  THEN
         ROWSP =  8.
         COLSP =  8.
         GO TO 1669
      END IF

1669  RATIO = (NROUND*LETHAL) / (ROWSP*COLSP*RF(IA,IT))
      PHI = 3.141592654
      A = ((LETHAL*NROUND)/(2*PHI))**.5
      PKILL = RATIO * (A*A/((A*A+RHOX**2)*(A*A+RHOY**2))**.5) *
     1       EXP(-.5*((MUX**2)/(A*A+RHOX**2) + (MUY**2)/(A*A+RHOY**2)))
      IFCAS = PKILL * RF(IA,IT) / 2.
      RETURN
      END
**********************************************************************
* IV-6. SUBROUTINE FOR COMPUTING CASUALTIES BY MINEFIELDS
**********************************************************************
      SUBROUTINE MFILD2 (IA,IT,MFANS,INCRE,NA,WID,TIME,RF,MFCAS)

      INTEGER  MFANS,INCRE,NA,NOPM,NOSM,WID
      REAL     TIME(NA),RF(4,0:1001),PCOEF,SCOEF,MFCAS,TPM,TSM

      DATA     NOPM ,NOSM   /300,200/
      DATA     TPM  ,TSM    /20.0,15.0/
      DATA     PCOEF,SCOEF  /.00020,.00015/

      IF(MFANS .EQ. 1) THEN
         MFCAS = (PCOEF*RF(IA,IT)*NOPM*(TPM/60.)) / (TIME(WID)/INCRE)
      ELSE IF(MFANS .EQ. 2) THEN
         MFCAS = (SCOEF*RF(IA,IT)*NOSM*(TSM/60.)) / (TIME(WID)/INCRE)
      END IF
      RETURN
      END
****************************************************************
* IV-7. SUBROUTINE FOR COMPUTING CASUALTIES BY DIRECT FIRE
****************************************************************
      SUBROUTINE DRFIR2 (DFANS,DFA,BRDIST,IA,IT,RF,BF,AR,RDFCAS,BDFCAS,
     1                  PLTN,RANGE,NNN,ACO,AMO)
      INTEGER  DFANS,DFA(4,1000),PLTN
      REAL     RF(4,0:1001),BF(4,0:1001),PLBP,FBF(0:1001)
      REAL     BRDIST,RANGE,RED,BLU,RDFCAS,BDFCAS,AR,BR,MU,PL

      DATA     PLBP           / 0.0/
      DATA     AOMEGA,BOMEGA  /0.50,1.00/
      DATA     AC,BC          /0.0380,0.0160/
      DATA     AM,BM          /0.23,0.00010/
      DATA     MU             /1.0/

      ACO = AC
      AMO = AM
      IF(NNN .GT. 0)  GO TO 1810
      PL = PLTN
1810  FBF(IT) = PL
C---FIND ENGAGED FORCES OF BOTH SIDES ON DIRECT FIRE BATTLE !
      RED = RF(IA,IT)
      BLU = BF(IA,IT)

C---CASE-#1 (MIXED LAW) : BLUE FORCE AMBUSHES THE RED FORCE !
      IF(DFANS .EQ. 1) THEN
         AR = AM * (1.0-BRDIST/RANGE)**MU
         BR = BM * (1.0-BRDIST/RANGE)**MU
         BLU = FBF(IT)
         IF(BLU .LT. PLBP)  THEN
            RDFCAS = 0.0
            BLU = 0.0
         ELSE
            RDFCAS = AR * BLU
         END IF
         BDFCAS = BR * BLU * RED
         FBF(IT) = BLU - BDFCAS
         PL = FBF(IT)
         NNN = NNN + 1
         GO TO 1900

C---CASE-#2 (HEMBOLT EQUTION) !
      ELSE IF(DFANS .EQ. 2) THEN
         IF(RED .LE. 0.  .OR.  BLU .LE. 0. )  THEN
            BDFCAS = 0.
            RDFCAS = 0.
            GO TO 1900
         END IF
         AR = AC * (1.0-BRDIST/RANGE)**MU
         BR = BC * (1.0-BRDIST/RANGE)**MU
         RDFCAS = AR*((RED/BLU)**(1.0-BOMEGA))*BLU
         BDFCAS = BR*((BLU/RED)**(1.0-AOMEGA))*RED
      END IF
1900  RETURN
      END
************************************************************************
* IV-8. SUBROUTINE FOR COMPUTING THE ADJUSTED SPEED BASED ON
*       THE NUMBER OF RED UNITS (BATTALIONS) ON ONE AVENUE.
************************************************************************
      SUBROUTINE  ASPED2 (I,IR,SPEED,ADSP)

      INTEGER  IR,AOA1(4),AOA2(3),AOA3(6)
      REAL     SPEED(44),ADSP(44)

      DATA     AOA1       /5,15,33,35/
      DATA     AOA2       /4,7,19/
      DATA     AOA3       /2,11,13,23,42,43/

         GO TO (201,202,203,204)  IR
201         ADSP(I) = SPEED(I)
            GO TO 2010
202         ADSP(I) = SPEED(I)
            DO 2011 J = 1,3
2011           IF(I .EQ. AOA2(J))  ADSP(I) = 0.9*SPEED(I)
            GO TO 2010
203         ADSP(I) = SPEED(I)
            DO 2012 J = 1,6
2012           IF(I .EQ. AOA3(J))  ADSP(I) = 0.9*SPEED(I)
            GO TO 2010
204         ADSP(I) = SPEED(I)
            DO 2013 J = 1,3
2013           IF(I .EQ. AOA2(J))  ADSP(I) = 0.8*SPEED(I)

2010  RETURN
      END
************************************************************************
* IV-9. SUBROUTINE FOR COMPUTING THE REDUCED SPEED
*       BASED ON EACH WEAPON TYPE.
************************************************************************
      SUBROUTINE  RSPED2 (IA,IT,NA,SPEED,TIME,DIST,WID,RANGE,AR,RF,
     1                    IFANS,MFANS,DFANS,OSPEED,ACO,AMO)

      INTEGER  NA,WID,IFANS,MFANS,DFANS
      REAL     AR,DIST(NA),SPEED(NA),TIME(NA),MINSPD,RF(4,0:1001)
      REAL     OSPEED(NA)

      DATA     MINSPD    /0.500/

      IF(IFANS .EQ. 1) THEN
         SPEED(WID) = DIST(WID)*60./(TIME(WID)+10.)
      END IF
      IF(MFANS .EQ. 1)  THEN
         SPEED(WID) = DIST(WID)*60./(TIME(WID)+20.)
      END IF
      IF(MFANS .EQ. 2)  THEN
         SPEED(WID) = DIST(WID)*60./(TIME(WID)+15.)
      END IF
      IF(DFANS .EQ. 1) THEN
         SPEED(WID) = SPEED(WID) * (1.0-AR/AMO) + MINSPD
         IF(SPEED(WID) .GT. OSPEED(WID))  SPEED(WID) = OSPEED(WID)
      END IF
      IF(DFANS .EQ. 2) THEN
         IF(RF(IA,IT) .EQ. 0.) THEN
            SPEED(WID) = 0.
         ELSE
            SPEED(WID) = SPEED(WID) * (1.0-AR/ACO) + MINSPD
            IF(SPEED(WID) .GT. OSPEED(WID))  SPEED(WID) = OSPEED(WID)
         END IF
      END IF
      RETURN
      END
**********************************************************************
* IV-10. SUBROUTINE TO FIND THE TIME AND LOCATION
*        WHEN RED FORCE REACH BREAK-POINT !
**********************************************************************
      SUBROUTINE  BREAK2 (IA,IT,NOC,WHOLD,RF,BF,RRESER,BREAKP,BREAKT)

      INTEGER RRESER
      REAL    BREAKP(4),BREAKT(4),WHOLD,RF(4,0:1001),BF(4,0:1001)

      RF(IA,IT) = 0.
      BF(IA,IT) = BF(IA,IT-1)
         IF(NOC .EQ. 0)  THEN
C           RF(IA,IT) = RF(IA,IT-1) + RRESER
            BREAKP(IA) = WHOLD
            BREAKT(IA) = IT
         END IF
      NOC = NOC + 1
1111  RETURN
      END
**********************************************************************
* IV-11. SUBROUTINE TO PRINT THE CASUALTIES AND SURVIVORS
*        FOR BOTH SIDES IN BATTLE2 TYPE.
**********************************************************************
      SUBROUTINE  PRINT2 (RBN,BCO,BLUEP1,BLUEP2,RRESER,PLTN,NA,
     1                   IFSUM,MFSUM,RDFSUM,BDFSUM,
     1                   TRCAS,TBCAS,TRSUR,TBSUR)

      INTEGER  RBN,BCO,BLUEP1,BLUEP2,NA,RRESER,PLTN
      REAL     IFSUM(4),MFSUM(4),RDFSUM(4),BDFSUM(4)
      REAL     TIFSUM,TMFSUM,TRDF,TBDF
      REAL     TRCAS,TRSUR,TBCAS,TBSUR

      TIFSUM = 0.0
      TMFSUM = 0.0
      TRDF = 0.0
      TBDF = 0.0

      TRCAS = 0.0
      TBCAS = 0.0
      TRSUR = 0.0
      TBSUR = 0.0

      DO 101 IA = 1,4
         TIFSUM = IFSUM(IA) + TIFSUM
         TMFSUM = MFSUM(IA) + TMFSUM
         TRDF = RDFSUM(IA) + TRDF
         TBDF = BDFSUM(IA) + TBDF
101   CONTINUE
      TRF = RBN*3.0 + RRESER
      TBF = BCO*3.0 + PLTN
      BFCAS1 = BDFSUM(1) + BDFSUM(2)
      BFCAS2 = BDFSUM(3) + BDFSUM(4)
      BFSUR1 = BLUEP1*BCO - BFCAS1
      BFSUR2 = BLUEP2*BCO - BFCAS2

      TRCAS = TIFSUM + TMFSUM + TRDF
      TRSUR = TRF - TRCAS
      TBCAS = TBDF
      TBSUR = TBF - TBCAS

      RETURN
      END
*************************************************************************
*  V. SUBROUTINE TO COMPUTE THE WEIGHTED UTILITY VALUES OF BLUE
*     SURVIVOR FOR EACH UTILITY FUNCTIONS !
*************************************************************************
      SUBROUTINE  UTIL (MR,MB,IB,VALUE,LIN,SQU,ROO)

      INTEGER  MR,MB
      REAL     VALUE(4),UL(4),US(4),UR(4)
      REAL     LIN,SQU,ROO,ALIN,WGT(4)

      DATA     WGT   /0.05,0.70,0.05,0.20/
      DATA     ALIN  /340.0/

      TEMP1 = 0.
      TEMP2 = 0.
      TEMP3 = 0.
C---UTILITY VALUES FOR THE BLUE SURVIVORS !
      DO 2301 K = 1,4
         UL(K)=(9./55.)*VALUE(K) + 10.
            IF(VALUE(K) .LE. ALIN)  UL(K)=(9./55.)*VALUE(K)
         US(K)=(1./3025.)*VALUE(K)**2.0
         UR(K)=(4.264014327)*VALUE(K)**0.5

         TEMP1 = WGT(K)*UL(K) + TEMP1
         TEMP2 = WGT(K)*US(K) + TEMP2
         TEMP3 = WGT(K)*UR(K) + TEMP3
2301  CONTINUE
      LIN = TEMP1
      SQU = TEMP2
      ROO = TEMP3
      RETURN
      END
```

APPENDIX E. EXEC FOR ADVANCED MODEL

This is a execution code of Fortran-77 for the advanced model in Appendix D.

```
FILEDEF 12 DISK THESIS DATA
EXEC WF77 ADVAN (NOEXT NOWAR
```

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